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# AN EVALUATION
# OF THE
# ATOMICS INTERNATIONAL
# MOLTEN CARBONATE PROCESS

PREPARED FOR
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
CONTRACT CPA 70-76

SB

SINGMASTER & BREYER
CHEMICAL & METALLURGICAL PROCESS ENGINEERS
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Previous experimental work and process criteria were reviewed. The removal of sulfur oxides from an 800 MW power plant operated with coal containing 3% sulfur was selected as a base case. Alternate cases involving coal-burning power plants included 2 additional capacities, 400 and 1000 MW, and coal sulfur contents of 1 and 6%. Various copper smelter situations were also reviewed. A smelter producing 200 tons per day of copper by a reverberatory furnace process was an alternate case. The molten carbonate process appears to be technically feasible. Process and engineering problem areas were identified and potential solutions were examined. The base power plant case, 800 MW at 3% coal sulfur, resulted in an estimated capital cost of $13.4 million, to achieve a 95% reduction in sulfur oxides emission. This capital cost was equivalent to approximately $17 per KW of station capacity. The annual operating cost including depreciation was estimated to be in the region of 0.9 mills per station KWH. The costs of a Claus Plant or credit for the value of the sulfur produced were not included. A description of the process, process and design criteria, and the assumptions that were made to estimate the costs for the base case sulfur oxides recovery plant are presented. Also, included for the base case are process and engineering flow diagrams, plant arrangement drawings, material balances, heat duties and process equipment specifications. An attempt was made to account for the chloride content of the coal, which would appear in the process melt as potassium chloride, both in solution and as a solid. The presence of potassium chloride was found to affect the costs and design of the fly ash filter, the reducer exit gas heat exchanger, and the cost of carbonate recovery from the filtered solids.

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Department of Health, Education, and Welfare

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By

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November 30, 1970

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## REPORT IN BRIEF

The Molten Carbonate Process for the removal of sulfur oxides from power plant stack gases has been evaluated by Singmaster & Breyer under Contract No. CPA 70-76, National Air Pollution Control Administration. This process was developed by Atomics International. Singmaster & Breyer reviewed the previous experimental work and process criteria in the course of making this evaluation. The purpose of the evaluation was to advise the sponsor on the continued course of action regarding this process.

The removal of sulfur oxides from an 800 MW power plant operated with coal containing 3% sulfur was selected as a base case for evaluation. Alternate cases were also evaluated from the results developed for the base case. Alternate cases involving coal-burning power plants included 2 additional capacities, 400 and 1000 MW, and coal sulfur contents of 1 and 6%. Various copper smelter situations were also reviewed. A smelter producing 200 tons per day of copper by a reverberatory furnace process was presented as an alternate case.

The Molten Carbonate Process appears to be technically feasible. Process and engineering problem areas were identified and potential solutions were examined. While there are evident solutions to known problem areas, these proposed solutions still remain to be demonstrated.

The evaluation of the base power plant case, 800 MW at 3% coal sulfur, resulted in an estimated capital cost of $13.4 million, to achieve a 95% reduction in sulfur oxides emission. This capital cost was equivalent to approximately $17 per KW of station capacity. The annual operating cost including depreciation was estimated to be in the region of 0.9 mills per station KWH.

The Molten Carbonate Process converts recovered sulfur oxides successively to sulfides and $H_2S$. The final step is the production of elemental sulfur from $H_2S$ gas by the Claus process. This present evaluation did not include the costs of a Claus Plant or credit for the value of the sulfur produced.

This report presents a description of the process, process and design criteria, and the assumptions that were made to estimate the costs for the base case sulfur oxides recovery plant. Also included for the base case are process and engineering flow diagrams, plant arrangement drawings, material balances, heat duties and process equipment specifications.

Costs and material balances for the alternate cases were derived from the base case. Sulfur oxide recovery, plant capital, and operating unit costs responded significantly to coal sulfur contents in the range 1 to 6% as described on Figure 1. Unit costs at 800 and 1000 MW plant capacity were essentially unchanged for a given coal sulfur content. The unit costs at 400 MW capacity increased significantly, according to these estimates.

Major process and engineering problem areas still requiring demonstrated solutions suitable for full scale application were identified as follows:

1. Elimination of melt carryover with the absorber offgas.

2. Liquid/gas absorber ratios and absorber design for effective sulfur oxides removal from flue gases.

3. Construction materials and fabrication of the process melt reducer, operating at the temperature of 1500°F.

4. The sequence of reduction reactions and the required internal design of the reducer.

5. Fly ash and coke filters capable of producing a low liquid content solids cake at the process temperature of 850°F.

6. The extent to which the carbonate components from solids filter cakes can be economically recovered.

This evaluation also attempted to account for the chloride content of the coal, which would appear in the process melt as potassium chloride, both in solution and as a solid. The presence of potassium chloride was found to affect the costs and design of the fly ash filter, the reducer exit gas heat exchanger, and the cost of carbonate recovery from the filtered solids.

Significant process tradeoffs that were developed during this evaluation include the following items:

1. Electrostatic precipitation of fly ash from flue gases at the process temperature of 850°F cost significantly less than precipitation at the lower conventional flue gas exit temperature of 325°F, followed by reheat to 850°F.

2. A high temperature electrostatic precipitator operating at 99.5% efficiency costs less than higher or lower efficiencies, as governed by downstream melt replacement costs at the fly ash filter.

3. Type 347 stainless steel for absorber construction was economically more favorable than low alloy steel, when both alloys were applied to compatible process designs.

4. Evaluation of reducer criteria showed that a horizontal, cylindrical vessel configuration with internal refractory lining was superior to other alternates at the reaction temperature of 1500°F.

5. Current market costs and availability now favor green delayed coke as a reducing agent to convert recovered sulfur oxides to sulfides, in place of fluidized petroleum coke.

6. The complete recovery of all carbonate melt components from filtered solids should be investigated further.

7. Preliminary estimates of smelter operation showed that it was more economical to replace an existing bag filter system with a high temperature (850°F) electrostatic precipitator. However, reheating of process flue gases to 850°F was more favorable for an existing electrostatic precipitator operating at 600°F.

A final evaluation and plant design for the Molten Carbonate Process requires further development to establish the characteristics and design for some steps in the process.

This report recommends continued development and evaluation of the process.

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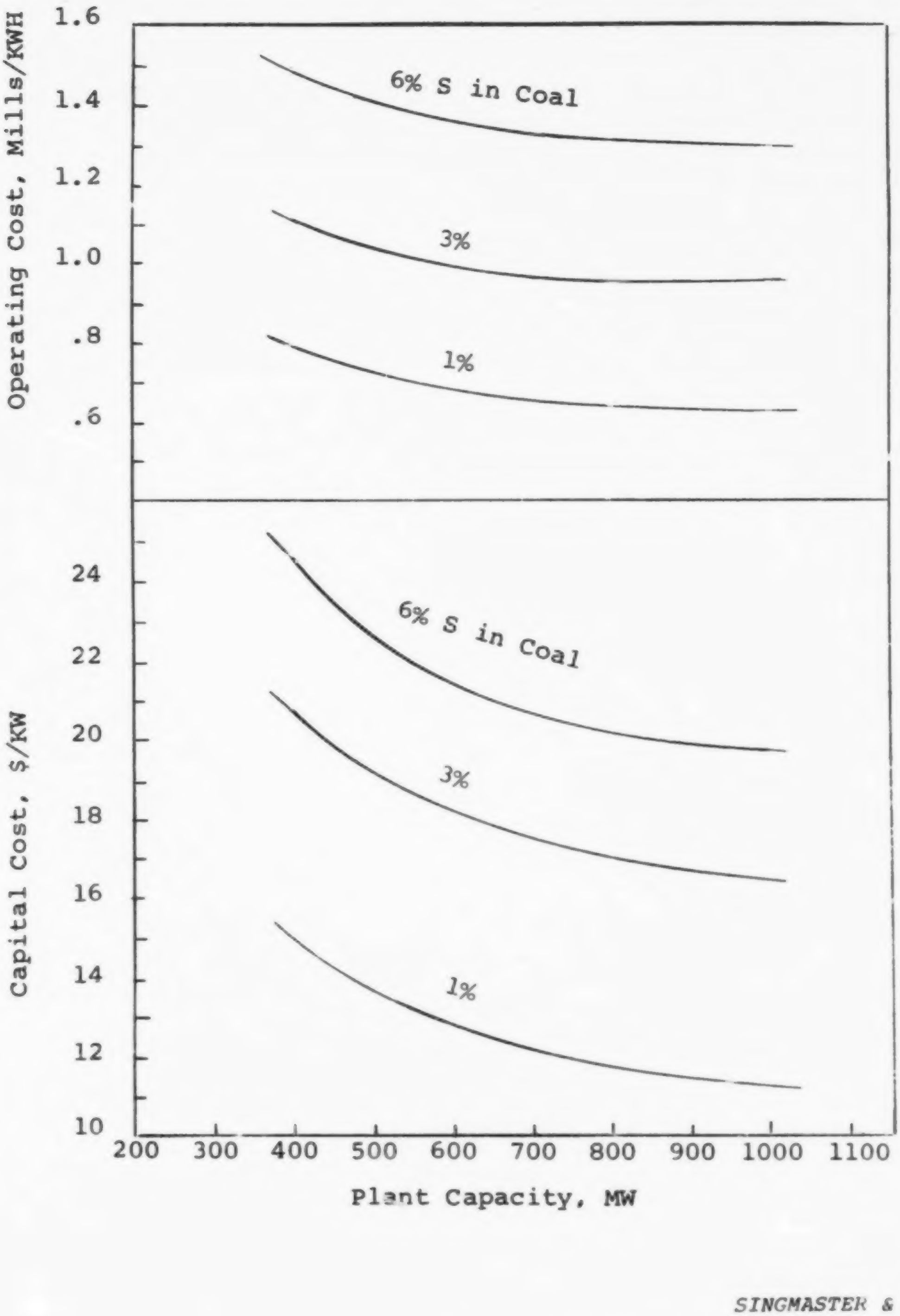
November 30, 1970

Figure 1. Capital Cost and Annual Operating Cost for $SO_x$ Removal vs. Plant Capacity for Various % S Coals



*SINGMASTER & BREYER*

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# 1. INTRODUCTION

This study was performed to review and evaluate The Atomics International Molten Carbonate Process for removal of $SO_2$ from coal burning power plant stack gases and from copper smelter gaseous effluents.

The overall process was examined and each process step was analyzed according to technical and economic considerations. From this analysis, a base case plant was defined for removal of $SO_2$ from an 800 MW power plant burning coal containing 3% sulfur, 0.04% chloride and 10% ash. Costs of $SO_2$ removal for alternate cases such as for one and six percent sulfur in coal and for 400 and 1000 MW power generating stations burning coal containing one, three and six percent sulfur were also estimated. In addition, the process was evaluated for removal of $SO_2$ contained in copper reverberatory furnace off-gas.

The evaluation excluded the capital and operating costs for a Claus Plant to recover elemental sulfur from the Molten Carbonate Process off-gas. Furthermore, no credits were allowed in the operating cost estimate for byproduct sulfur recovery or for the use of high sulfur coal.

## 2. RECOMMENDATIONS

Our recommendations are based on the technical aspects of the process. We have not compared the cost of this process to competitive processes nor have we considered:

1) the future availability and price of raw materials.

2) the effect of possible release to the atmosphere of carbonate from the boiler stack if the melt is carried over with the absorber off-gas, and

3) the discharge of soluble salt solutions from the lithium carbonate recovery process.

The process appears to be feasible; however, certain problem areas have been uncovered which should be defined in a thoughtful pilot program where corrective measures can be tested. A complete technical and economic evaluation of the process can only be performed after the pilot program is completed.

It is therefore recommended that development and evaluation of the process be continued. We believe that a pilot plant is the next logical step in this development. Operation of a materials test loop can either precede the pilot plant or be carried out as a study parallel to the pilot plant program depending on time and funds available to the program.

The development program and materials test loop should be planned to:

1) Confirm the selection of construction materials

2) Confirm equipment design criteria

3) Confirm process performance and reaction yields

4) Estimate equipment operating cycles

5) Determine maintenance requirements

6) Determine control and monitoring procedures

7) Identify equipment components requiring intensive development

The pilot plant should be designed to scrub $SO_2$ from flue gases from an existing power plant preferably burning both coal and fuel oil. The recommendation for a combination fired boiler is based on initially running the pilot plant with flue gases produced from fuel oil firing to minimize the problems associated with coal fly ash. However, location at a power plant firing only coal would merely mean a rearrangement of priorities in the fields of investigation.

In order to minimize boiler downtime, we recommend that the flue gas be taken from the stack and reheated to absorber temperature by direct combustion of low ash fuel. Depending upon the capacity of the pilot plant it may be advisable to include an indirect exchanger to recover some of the heat available in the absorber off-gas to reduce operating costs; but, this should be evaluated during the planning of the pilot plant.

The absorber is the critical step in the process for it is here that the $SO_2$ must be removed from the flue gas with a minimum amount of melt carried off with absorber exit gases. As a minimum program, the absorber must be tested to determine scrubber efficiency, nozzle performance, and demister efficiency; but, the amount of melt required to carry out these tests only may be substantial and, it will probably be necessary to regenerate the melt on a campaign basis to minimize these raw material costs. The demonstration absorber should be sized so that the wall effects that were evident in the bench scale tests will be negligible.

The remainder of the process steps can be designed to operate on a campaign basis which will require suitable surge capacity between the steps. The equipment required for the remaining process steps need not be designed for the same melt rate as the absorber.

The pilot work on filtration should be directed to increasing the filter cake thickness consistent with acceptable pressure drops across the filter cake. This will aid in minimizing capital costs and may reduce melt losses associated with discarded filter cake.

The operability of the two-zone reducer must be determined in the pilot plant. The design parameters must also be confirmed as well as the best method for introducing coke into the reducer. The advantage of a two-zone reducer lies in the effect of a more concentrated stream of carbon dioxide on the design and performance of the regenerator and the effect of a more concentrated stream of hydrogen sulfide on the capital cost and performance of the Claus Plant. A concentrated stream of carbon dioxide can be obtained in other ways.

Regenerator testwork should be directed to confirm the equilibrium data. The pilot plant regenerator should be provided with spare trays of different types that can be installed with the minimum amount of field modifications to test their efficiency. The regenerator off-gases can be incinerated and sent to the stack; it is not necessary to include a small Claus Plant for recovery of the sulfur since the gas analysis can be used in the design of a Claus Plant to be installed in a commercial size plant.

Initially, no waste heat recovery systems should be installed but appropriate test units should be included in the pilot plant to determine the problems associated with this heat recovery.

Recovery of lithium salts should not be attempted, however, laboratory work should parallel the pilot plant work to develop a suitable process for recovery of not only the lithium salts but sodium and potassium salts as well.

## 3. PROCESS DESCRIPTION

### a. General

The Atomics International Molten Carbonate Process for removal of $SO_x$ from power plant flue gases is depicted on the attached process flow diagram, Drawing PS-218-0001. This is the conceptual scheme for all cases under consideration. Some modifications are possible and these variations as well as the reasons for selection of the process scheme are discussed in later sections of this report. The material balance on the process flow diagram is for the base case power plant operating at 800 MW and burning coal containing three percent sulfur.

The attached engineering flow diagrams: -

| | |
|---|---|
| PS-218-0002 | $SO_x$ Removal |
| PS-218-0003 | Coke Handling Facilities |
| PS-218-0004 | $Li_2CO_3$ Recovery |

along with the plant arrangement drawings in Section 8 of this report form the basis for the capital and operating cost estimates for removal of $SO_x$ from the base case power plant flue gases.

### b. Process Description

In essence, the process consists of scrubbing the flue gas with a molten mixture of lithium, potassium, and sodium carbonates (minimum melting point 750°F). The melt, containing up to 32% sulfite salts, is regenerated by heating to 1500°F where the sulfates formed by disproportionation of the sulfites can be reduced to sulfides with carbon. The sulfides in the melt are converted back to carbonates with the formation of hydrogen sulfide by reaction at 850-900°F with carbon dioxide and steam.

### 1) $SO_x$ Removal - Drawing PS-218-0002

### Absorber

Flue gases taken before the economizer section of the boiler are passed through four electrostatic precipitator sections operating in parallel at 800-850°F where 99.5 percent of the fly ash is removed. The gases are sent from each precipitator to an associated absorber for removal of the $SO_x$ by the molten carbonate stream and are returned to the economizer section of the boiler.

The absorber reactions can be expressed as:

$$SO_2 + M_2CO_3 \longrightarrow M_2SO_3 + CO_2$$

$$SO_3 + M_2CO_3 \longrightarrow M_2SO_4 + CO_2$$

where M represents the eutectic mixture of sodium, potassium and lithium cations.

Some of the $M_2SO_3$ may be oxidized to the sulfate by the oxygen in the flue gas as follows:

$$M_2SO_3 + \frac{1}{2}\ O_2 \longrightarrow M_2SO_4$$

All sulfides are also oxidized to sulfate as follows:

$$M_2S + 2O_2 \longrightarrow M_2SO_4$$

The melt from the first absorber, V-1A, flows by gravity into one pump tank, V-2A, and is recirculated by P-1A to the absorber. The net increase of returned melt into the absorber circuit from the Regenerator System is pumped under level control to the recirculating line of Absorber V-1B. The melt then proceeds under level control in series from one absorber pump tank to the next absorber. Essentially, the flue gases flow in parallel and the melt flows in series through the absorbers. The $M_2CO_3$ content of the melt leaving the last absorber is maintained above 68 mol percent to keep the freezing point of the melt below 800°F.

Each pump tank is sized to hold all the liquid drained from its associated equipment. Each is also equipped with electrical heaters to remelt frozen process liquid in the event of a plant shutdown.

### Fly Ash Filtration

The melt from the last absorber pump tank, V-2D, is pumped under level control to one of two parallel fly ash filters, F-1, where the fly ash is removed from the process melt and sent to the $Li_2CO_3$ Recovery Process. When the pressure drop through the first filter exceeds an allowable limit the second filter is brought into operation.

The filtered melt is then split into streams, each under flow control, for charging to each of four reducers.

### Reducers

Each reducer is a two-compartment vessel - one an oxidation zone and the other reduction a zone with liquid passage between the two compartments for internal melt recirculation.

The endothermic heat for the reduction and the sensible heat required to raise the melt, coke and air to the reduction temperature of 1500°F is provided by the oxidation of $M_2S$ in the oxidation zone of the reducers.

At 1500°F the $M_2SO_3$ in the melt disporportionates to $M_2SO_4$ and $M_2S$. The $M_2SO_4$ is reduced in the reduction zone to $M_2S$ by the carbon contained in the coke. Part of the reduction zone melt is recycled to the oxidation zone to oxidize the $M_2S$ and provide the necessary heat. The oxidation zone melt also recycles back to the reduction zone to convert the $M_2SO_4$ to $M_2S$.

The reactions in the reducer may be expressed as follows:

Oxidation: $M_2S + 2O_2 \longrightarrow M_2SO_4$

$C + O_2 \longrightarrow CO_2$

Reduction: $M_2SO_4 + 2C \longrightarrow M_2S + 2CO_2$

Disproportionation: $4M_2SO_3 \longrightarrow 3M_2SO_4 + M_2S$

Coke S Recovery: $S + \frac{1}{2}C + M_2CO_3 \longrightarrow M_2S + 3/2\ CO_2$

The air for the oxidation zone is provided by the combustion air blowers, B-1. These blowers develop sufficient head to overcome the pressure drop of the reducer, exchanger and regenerator and to supply the Claus Plant with gas at 3 inches W.G. The combustion air is preheated in E-2 by oxidation zone off-gas to at least 600°F and admitted to the oxidation zone of the reducer through sparger pipes. As conceived, coke is charged to the reduction zone by pneumatic blow tanks.

The oxidation zone off-gas is used to preheat the incoming combustion air before being sent to the boiler with the absorber off-gas. The reduction zone off-gas, consisting essentially of $CO_2$, is used in the Regenerator. An excess of $CO_2$ is produced in this zone and the excess is diverted to the oxidation zone off-gas stream. An equimolar quantity of $H_2O$ and $CO_2$ is required for the regeneration step. The $H_2O$ is supplied to the $CO_2$ stream by direct injection of both water and/or steam to reduce the temperature of the $CO_2$ stream from the 1500°F level to the required regenerator temperature of 850°F. The steam is assumed to be available from the waste heat boiler in the Claus Plant.

The melt from the reducer at 1500°F is cooled to 950°F by recirculating 850°F reduced melt from the Reducer Product Cooler. This recirculation is controlled by the temperature of the melt in the Reducer Quench Tank.

The melt from the Reducer Quench Tank is pumped through the cooler and is recirculated as mentioned above. The net excess of melt flows under level control to the coke filters.

## Coke Filtration

The melt from the reduction step flows to one of two parallel coke filters, F-2, where the unreacted coke is removed from the process melt and sent to the $Li_2CO_3$ Recovery Process. Flow is diverted to the second filter when the pressure drop through the first unit exceeds the allowable limit.

The filtered melt is then sent to the Regenerator.

## Regeneration

The regeneration reaction is expressed as:

$$M_2S + CO_2 + H_2O \longrightarrow M_2CO_3 + H_2S$$

The regenerator is a tower consisting of 15 bubble cap trays where the melt is added to the top of the column and is contacted with the $CO_2$ and $H_2O$ rising up the tower.

The regeneration is exothermic and coolers are provided to remove this heat. The intermediate cooler takes the total flow of the upper section of the tower and returns a portion of this flow under temperature control to the upper section to cool the tower. The remainder of the cooled melt is sent under level control to the lower section of the regenerator.

The bottoms cooler acts in the same manner as the intermediate cooler to cool the lower section of the regenerator. The cooled bottoms which are not recirculated to the regenerator are returned under level control to the absorber.

The gases from the Regenerator at 3 inches W.G. containing $H_2O$, $CO_2$ and $H_2S$ are sent to a Claus Plant for recovery of sulfur.

### $M_2CO_3$ Makeup

The eutectic mixture of $M_2CO_3$ required for the initial charge and makeup is prepared in the $M_2CO_3$ melt tank, V-9.

The sodium, potassium and lithium carbonates are received by truck and fed to individual silos each with a nominal four-day storage capacity. The lithium carbonate which is recovered in the $Li_2CO_3$ Recovery Process is also stored in the $Li_2CO_3$ silo.

Each melt component is fed under weigh control to V-9 which is electrically heated to melt the solid. The tank has a nominal 16-hour capacity which permits charging of the tank during daylight hours only.

The melt is fed to the process under flow control.

### 2) Coke Handling Facilities - Drawing PS-218-0003

Green delayed coke of minus 2 inch size is delivered in rail cars and is fed to a crusher to reduce its size to minus 1/4 inch. The crushed coke is screened and the oversize returned in closed circuit to the crusher. The undersize material is charged to two coke silos with a total of 4 days live storage capacity.

The coke is withdrawn from the silos and fed by belt conveyors to a coke bin associated with each reducer.

### 3) $Li_2CO_3$ Recovery Process - Drawing PS-218-0004

The recovery process as conceived has been developed by Atomics International. However, in the process concept which has been evaluated, filtrations are carried out continuously and reactions are batch operations. It has been assumed that the chlorides and heavy metals to be removed from the Molten Carbonate Process report with the fly ash and coke filter cakes, respectively.

The fly ash and coke filter cakes from the Molten Carbonate Process are quenched with water and charged to T-110 where the soluble salts are dissolved. The slurry is pumped to a rotary drum vacuum filter, F-101 and the insoluble fly ash, coke and lithium carbonate are removed as the cake. The dissolved salts containing the chlorides are removed as filtrate.

The cake is slurried with returned filtrate from F-103 or with water and is held in T-102 to await the completion of the batch reaction in the $LiHCO_3$ Reactor, V-101. The slurry is pumped to V-101 and $CO_2$, prepared in an inert gas generator, is bubbled through under back pressure control to convert the insoluble $Li_2CO_3$ to soluble $LiHCO_3$. The $CO_2$ is maintained under approximately 20 psi partial pressure.

The carbon dioxide required for the conversion to $LiHCO_3$ can possibly be supplied from either the excess gas available from the reducer or from power plant flue gases. These alternate sources were not considered in the evaluation in order to separate the $Li_2CO_3$ Recovery Facilities from the Molten Carbonate Process and the power plant.

The contents of V-101 are discharged to the surge tank, T-103 to permit charge of the next reactor batch. The reactor product is filtered in the filter, F-102 and the fly ash and coke filter cakes containing the heavy metals are slurried with the filtrate of F-101, in T-101 and sent to disposal along with the fly ash from the electrostatic precipitator.

The filtrate of F-102 is pumped to the $Li_2CO_3$ Reactor, V-101, where hot air is added to convert the soluble $LiHCO_3$ to the insoluble $Li_2CO_3$. After the conversion is complete, the reactor is emptied into the surge tank, T-104 and a new batch is added to the reactor.

The $Li_2CO_3$ slurry in T-104 is continuously pumped to the $Li_2CO_3$ Filter, F-103. In order to recover any soluble lithium values, the filtrate from F-103 is recycled in the process and used to slurry the filter cake from F-101. The wet lithium carbonate filter cake from F-103 is dried and conveyed to the $Li_2CO_3$ silo, T-5, for use as makeup in the Molten Carbonate Process.

#### 4) Instrumentation

The instrumentation to monitor and control the process steps is shown on the engineering flow diagrams. This instrument concept may have to be modified after experience is gained in operations of a pilot plant or a commercial plant.

### c. Basis for Material Balance

The material balance for the base case plant (800 MW power plant burning 280 tons per hour of coal containing three percent sulfur and 0.04 percent chlorine) which is shown on the Process Flow Diagram - Drawing No. PS-218-0001 is based on the following:

#### 1) Coal Combustion

The coal analysis is shown as follows, based on a typical analysis used by Atomics International. The oxygen content in the coal was adjusted to allow a typical chlorine content of 0.04%.

| Coal Component | Composition Weight % |
|---|---|
| C | 70.00 |
| H | 4.80 |
| O | 5.76 |
| S | 3.00 |
| Cl | 0.04 |
| N | 1.40 |
| Ash | 10.00 |
| Moisture | 5.00 |
|  | 100.00 |

Assumptions used to calculate the boiler flue gas compositions are:

Excess Air - 20%
95% combustion of S
90% of Cl volatilized to HCl
85% of ash entrained with the boiler flue gas
95% combustion of C (unburned C remains in furnace ash)
100% combustion of H
100% volatilization of O, N and $H_2O$

2) Process Conditions

a) All process chemical conversions are 95% except:

1. $M_2S$ oxidation in absorber - 100%.

2. $M_2SO_3$ disproportionation downstream of absorber - 10%.

3. $M_2SO_3$ disproportionation in reducer - 100%.

b) $M_2CO_3$ mol concentration at absorber exit, 68.0%. This is a minimum allowable value.

c) Absorber recycle ratio, 1:1 (mols of liquid recycled to absorber: mols of liquid entering reducer). This ratio is specified as a target. (Maximum allowable recycle ratio is 3:1. Pumps to be sized for 3:1 recycle).

d) The saturation concentration of KCl in process melt is 3.0 weight percent at the regenerator inlet, the point of lowest solubility.

e) All process streams are nominally 850°F, except where noted.

f) Other assumptions used in this calculation are listed as follows:

Precipitator

99.5% fly ash removal.

Absorber

95% removal of residual $SO_x$, fly ash, and HCl conversion to KCl.

$SO_x$ consists of 90 mol % $SO_2$ and 10 mol % $SO_3$.

All entering $M_2S$ is oxidized to $M_2SO_4$, with the consumption of $O_2$ from the flue gas.

HCl is converted to insoluble KCl, with the equivalent consumption of $K_2CO_3$ from the melt.

Fly ash Filter

Melt content of fly ash filter cake, 65 weight percent.

### Reducer

Inlet air 600°F, and coke at 70°F

Reducer temperature, 1500°F.

The heat generation for the reduction reaction was derived by air oxidation of equimolar quantities of $M_2S$ and carbon in coke. Complete consumption of carbon and oxygen for oxidation was assumed and reduction of $M_2SO_4$ by carbon was assumed to be 95% complete.

95% sulfur in the coke converted to $M_2S$. (Unconverted coke sulfur remains as solid residue).

Coke Analysis:

| Component | Composition Weight,% |
|---|---|
| C | 81.6 |
| S | 6.0 |
| Ash | 0.4 |
| Volatiles | 12.0 |
| | 100.0 |

### Coke Filter

Melt content in filter cake, 50 weight percent.

### Regenerator

Inlet $CO_2$ and $H_2O$ at 85% stoichiometric excess.

### d. Utilities for Base Case

The utilities required for the base case plant are:

1) Water

| | |
|---|---|
| Process Water(Boiler Feed Water Preferred) | |
| Regenerator | 12 GPM |
| Raw Water | |
| Miscellaneous Requirements (including Lithium Carbonate Recovery) | 100 GPM |

2) Steam (Assumed available from Claus Plant)

| | |
|---|---|
| Regenerator | 12,000 #/Hr |

3) Fuel (Natural Gas)

| | |
|---|---|
| For Lithium Carbonate Recovery Process | |
| $Li_2CO_3$ Dryer | 800 SCFH |
| Inert Gas Generator | 8,000 SCFH |
| Total | 8,800 SCFH |

4) Power

| | |
|---|---|
| Approximate Motor Operating Load (See Motor List-Section 7) | 2,100 KW |
| Heat Tracing | 175 KW |
| Lighting | 25 KW |
| Total Average Load | 2,300 KW |
| Differential Power for High Temperature Electrostatic Precipitator | 1,980 KW |
| Differential Power for Boiler I.D. Fan | 950 KW |
| Total | 5,230 KW |

## e. Heat and Material Balances for Alternate Cases

The heat and material balance for the base case plant (800 MW with 3 percent sulfur in coal) is shown on the Process Flow Diagram - Drawing No. PS-218-0001. Heat and material balances for other power plant capacities and sulfur content of coal have been prepared and are listed on the attached tables. In addition, a material balance for a hypothetical copper smelter is also presented.

The attached tables list only the important streams in the process which can be identified by referring to the Process Flow Diagram.

The cases that have been considered are:

| Case No. | Flue Gas From | Plant Capacity |
|---|---|---|
| 1(Base) | Power Plant | 800 MW - 3% S in Coal |
| 2 | Power Plant | 800 MW - 1% S in Coal |
| 3 | Power Plant | 800 MW - 6% S in Coal |
| 4 | Power Plant | 400 MW - 3% S in Coal |
| 5 | Power Plant | 400 MW - 1% S in Coal |
| 6 | Power Plant | 400 MW - 6% S in Coal |
| 7 | Power Plant | 1000 MW - 3% S in Coal |
| 8 | Power Plant | 1000 MW - 1% S in Coal |
| 9 | Power Plant | 1000 MW - 6% S in Coal |
| 10 | Copper Smelter Reverberatory Furnace | 200 T/D copper |

## MATERIAL BALANCE

Case No. 2. 800 MW, 1.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 142 | | 7 | | | | | |
| $SO_3$ | #Mol/hr | 16 | | 1 | | | | | |
| HCl | #Mol/hr | 5 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 33900 | 181 | 34100 | | 326 | | 329 | 160 |
| $H_2O$ | #Mol/hr | 7500 | 25 | 7500 | | | | 329 | 160 |
| $O_2$ | #Mol/hr | 7900 | | 7900 | | | | | |
| $N_2$ | #Mol/hr | 179100 | 864 | 180000 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 20 | | 20 | 20 |
| $H_2S$ | #Mol/hr | | | | | | | | 162 |
| Total | #Mol/hr | 228600 | 1070 | 229500 | | 346 | | 678 | 502 |
| Fly Ash | #/hr | 238 | | 11.9 | | | | | |
| **Process Gas Input** | | | | | | | | | |
| Air | #Mol/hr | | | | 1116 | | | | |
| Water | #Mol/hr | | | | | | 108 | | |
| Steam | #Mol/hr | | | | | | 221 | | |
| Temp., $^{o}F$ | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 1444 | 6.8 | 1450 | 7.0 | 2.2 | 2.1 | 4.3 | 3.2 |

## MATERIAL BALANCE

Case No. 2. 800 MW, 1.0% Sulfur in Coal.
Coke Rate, 7600 lb/hr

| Stream No. | | 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Melt Components** | | | | | | | | | | |
| $M_2S$ | #Mol/hr | 0 | 3 | 12 | 3 | 172 | 170 | 8 | 1.0 | 0.1 |
| $M_2SO_3$ | #Mol/hr | 258 | 116 | 116 | 114 | 0 | 0 | 0 | 0.0 | 2.3 |
| $M_2SO_4$ | #Mol/hr | 82 | 48 | 55 | 48 | 7 | 7 | 7 | 0.0 | 1.1 |
| $M_2CO_3$ | #Mol/hr | 816 | 408 | 976 | 401 | 387 | 386 | 568 | 2.2 | 7.4 |
| KCl, Dissolved | #Mol/hr | 44 | 22 | 44 | 22 | 22 | 22 | 22 | 0.1 | 0.4 |
| Total | | 1200 | 599 | 1203 | 588 | 588 | 585 | 605 | 3.3 | 11.3 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 821.8 | 410.9 | 410.9 | 4.1 | 4.1 | 0.0 | 0.0 | 4.1 | 406.8 |
| Fly Ash | #/hr | 461.4 | 230.7 | 230.7 | 2.3 | 2.3 | 0.0 | 0.0 | 2.3 | 228.4 |
| Coke Residue | #/hr | 6.0 | 3.0 | 6.0 | 0.1 | 294.1 | 3.0 | 3.0 | 291.1 | 3.0 |
| Total | #/hr | 1289.2 | 644.6 | 647.6 | 6.5 | 300.5 | 3.0 | 3.0 | 297.5 | 638.2 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 120 | 60 | 120 | 59 | 59 | 58 | 60 | - | - |

Heat Exchanger Duties, MM Btu/hr

E-1: 15.4
E-2: 6.0
E-4: 3.2
E-5: 4.8

(1) Includes Stream 30, #Mol/hr

$Li_2CO_3$, 4.2
$Na_2CO_3$, 3.0
$K_2CO_3$, 5.1
12.3

## MATERIAL BALANCE

Case No. 3. 800 MW, 6.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 896 | | 45 | | | | | |
| $SO_3$ | #Mol/hr | 100 | | 5 | | | | | |
| HCl | #Mol/hr | 6 | | 1 | | | | | |
| $CO_2$ | #Mol/hr | 28500 | 1086 | 29586 | | 1974 | | 1974 | 960 |
| $H_2O$ | #Mol/hr | 21500 | 148 | 21648 | | | | 1974 | 960 |
| $O_2$ | #Mol/hr | 7200 | | 7200 | | | | | |
| $N_2$ | #Mol/hr | 162000 | 5182 | 167200 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 120 | | 120 | 120 |
| $H_2S$ | #Mol/hr | | | | | | | | 1014 |
| Total | #Mol/hr | 220200 | 6416 | 225700 | | 2094 | | 4068 | 3054 |
| Fly Ash | #/hr | 238.0 | | 11.9 | | | | | |
| Process Gas Input | | | | | | | | | |
| Air | #Mol/hr | | | | 6698 | | | | |
| Water | #Mol/hr | | | | | | 648 | | |
| Steam | #Mol/hr | | | | | | 1326 | | |
| Temp. °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 1392 | 40.5 | 1.4 | 42.3 | 13.3 | 12.5 | 25.7 | 19.3 |

# MATERIAL BALANCE

Case No. 3. 800 MW, 6.0% Sulfur in Coal.
Coke Rate, 45500 lb/hr

| | | Stream No. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Melt Components | | 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
| $M_2S$ | #Mol/hr | 0 | 19 | 72 | 19 | 1066 | 1060 | 53 | 6.2 | 0.1 |
| $M_2SO_3$ | #Mol/hr | 1547 | 696 | 696 | 694 | 0 | 0 | 0 | 0.0 | 2.4 |
| $M_2SO_4$ | #Mol/hr | 524 | 315 | 357 | 314 | 42 | 42 | 42 | 0.2 | 1.1 |
| $M_2CO_3$ | #Mol/hr | 4944 | 2472 | 5894 | 2464 | 2383 | 2370 | 3422 | 12.8 | 7.6 |
| KCl, Dissolved | #Mol/hr | 256 | 128 | 256 | 128 | 128 | 127 | 127 | 0.8 | 0.4 |
| Total | | 7272 | 3630 | 7275 | 3619 | 3619 | 3599 | 3644 | 20.0 | 11.6 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 821.8 | 410.9 | 410.9 | 4.1 | 4.1 | 0 | 0 | 4.1 | 406.8 |
| Fly Ash | #/hr | 461.4 | 230.7 | 230.7 | 2.3 | 2.3 | 0 | 0 | 2.3 | 228.4 |
| Coke Residue | #/hr | 36.0 | 18.0 | 36.0 | 0.2 | 1764.2 | 17.6 | 17.6 | 1746.6 | 17.8 |
| Total | #/hr | 1319.2 | 659.6 | 677.6 | 6.6 | 1770.6 | 17.6 | 17.6 | 1753.0 | 653.0 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 727 | 363 | 728 | 362 | 362 | 360 | 364 | - | - |

Heat Exchanger Duties, MM BTU/HR

E-1: 94.1
E-2: 36.0
E-4: 20.0
E-5: 30.0

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 8.8 |
| $Na_2CO_3$, | 6.4 |
| $K_2CO_3$, | 7.9 |
| | 23.1 |

## MATERIAL BALANCE

Case No. 4. 400 MW, 3.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 224 | | 11 | | | | | |
| $SO_3$ | #Mol/hr | 25 | | 2 | | | | | |
| HCl | #Mol/hr | 3 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 15500 | 272 | 15800 | | 494 | | 494 | 240 |
| $H_2O$ | #Mol/hr | 9800 | 37 | 9800 | | | | 494 | 240 |
| $O_2$ | #Mol/hr | 4200 | | 4200 | | | | | |
| $N_2$ | #Mol/hr | 87800 | 1296 | 89100 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 30 | | 30 | 30 |
| $H_2S$ | #Mol/hr | | | | | | | | 254 |
| Total | #Mol/hr | 117600 | 1605 | 118900 | | 524 | | 1018 | 764 |
| Fly Ash | #/hr | 119.7 | | 6.0 | | | | | |
| **Process Gas Input** | | | | | | | | | |
| Air | #Mol/hr | | | | 1674 | | | | |
| Water | #Mol/hr | | | | | | 162 | | |
| Steam | #Mol/hr | | | | | | 332 | | |
| Temp., °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 742 | 10.1 | 751 | 10.6 | 3.3 | 3.1 | 6.4 | 4.8 |

## MATERIAL BALANCE

Case No. 4. 400 MW, 3.0% Sulfur in Coal.
Coke Rate, 11400 lb/hr

| | | Stream No. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Melt Components | | 14 | 15 | 17 | 18 | 19 | 23 | 26[1] | 31 | 32 |
| $M_2S$ | #Mol/hr | 0 | 5 | 18 | 5 | 268 | 266 | 12 | 1.5 | 0.0 |
| $M_2SO_3$ | #Mol/hr | 387 | 174 | 174 | 173 | 0 | 0 | 0 | 0.0 | 1.2 |
| $M_2SO_4$ | #Mol/hr | 134 | 82 | 92 | 81 | 10 | 10 | 10 | 0.0 | 0.6 |
| $M_2CO_3$ | #Mol/hr | 1245 | 622 | 1482 | 619 | 600 | 596 | 860 | 3.2 | 3.7 |
| KCl, Dissolved | #Mol/hr | 65 | 32 | 65 | 32 | 32 | 32 | 32 | 0.2 | 0.2 |
| Total | | 1831 | 915 | 1831 | 910 | 910 | 904 | 914 | 4.9 | 5.7 |
| Solids | | | | | | | | | | |
| KCl | #/hr | 410.9 | 205.4 | 205.4 | 2.0 | 2.0 | 0.0 | 0.0 | 1.8 | 196.3 |
| Fly Ash | #/hr | 230.7 | 115.4 | 115.4 | 1.2 | 1.2 | 0.0 | 0.0 | 1.6 | 112.6 |
| Coke Residue | #/hr | 9.0 | 4.5 | 9.0 | 0.0 | 441.1 | 4.4 | 4.4 | 435.2 | 4.4 |
| Total | #/hr | 650.6 | 325.3 | 329.8 | 3.2 | 444.3 | 4.4 | 4.4 | 438.6 | 313.3 |
| Temp., $^{o}$F | | 850 | 850 | 850 | 850 | 1500 | 850 | 850 | 850 | 850 |
| Nominal Flow rate, gpm | | 183 | 92 | 183 | 91 | 91 | 90 | 91 | - | - |

Heat Exchanger Duties, MM Btu/hr

| | |
|---|---|
| E-1: | 23.7 |
| E-2: | 9.0 |
| E-4: | 5.0 |
| E-5: | 7.5 |

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 3.0 |
| $Na_2CO_3$, | 2.2 |
| $K_2CO_3$, | 3.1 |
| | 8.3 |

# MATERIAL BALANCE

Case No. 5. 400 MW, 1.0% Sulfur in Coal

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 71 | | 4 | | | | | |
| $SO_3$ | #Mol/hr | 8 | | 0 | | | | | |
| HCl | #Mol/hr | 3 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 17000 | 90 | 17000 | | 163 | | 164 | 80 |
| $H_2O$ | #Mol/hr | 3800 | 12 | 3800 | | | | 164 | 80 |
| $O_2$ | #Mol/hr | 4000 | | 4000 | | | | | |
| $N_2$ | #Mol/hr | 89500 | 432 | 90000 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 10 | | 10 | 10 |
| $H_2S$ | #Mol/hr | | | | | | | | 81 |
| Total | #Mol/hr | 114400 | 534 | 114800 | | 173 | | 338 | 251 |
| Fly Ash | #/hr | 119.0 | | 6.0 | | | | | |
| **Process Gas Input** | | | | | | | | | |
| Air | #Mol/hr | | | | 558 | | | | |
| Water | #Mol/hr | | | | | | 54 | | |
| Steam | #Mol/hr | | | | | | 110 | | |
| Temp. °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 722 | 3.4 | 725 | 3.5 | 1.1 | 1.0 | 2.2 | 1.6 |

## MATERIAL BALANCE

Case No. 5. 400 MW, 1.0% Sulfur in Coal.
Coke Rate, 3800 lb/hr

| Melt Components | | Stream No. 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| $M_2S$ | #Mol/hr | 0 | 2 | 6 | 2 | 86 | 85 | 4 | 0.5 | 0.0 |
| $M_2SO_3$ | #Mol/hr | 129 | 58 | 58 | 57 | 0 | 0 | 0 | 0.0 | 1.2 |
| $M_2SO_4$ | #Mol/hr | 41 | 24 | 28 | 24 | 4 | 4 | 4 | 0.0 | 0.6 |
| $M_2CO_3$ | #Mol/hr | 408 | 204 | 488 | 200 | 193 | 193 | 284 | 1.1 | 3.7 |
| KCl, Dissolved | #Mol/hr | 22 | 11 | 22 | 11 | 11 | 11 | 11 | 0.0 | 0.2 |
| Total | | 600 | 299 | 602 | 294 | 294 | 293 | 303 | 1.6 | 5.7 |
| Solids | | | | | | | | | | |
| KCl | #/hr | 410.9 | 205.4 | 205.4 | 2.0 | 2.0 | 0.0 | 0.0 | 2.0 | 293.4 |
| Fly Ash | #/hr | 230.7 | 115.4 | 115.4 | 1.2 | 1.2 | 0.0 | 0.0 | 1.2 | 114.2 |
| Coke Residue | #/hr | 3.0 | 1.5 | 3.0 | 0.0 | 147.0 | 1.5 | 1.5 | 145.6 | 1.5 |
| Total | #/hr | 644.6 | 322.3 | 323.8 | 3.2 | 150.2 | 1.5 | 1.5 | 148.8 | 319.1 |
| Temp., $^oF$ | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 60 | 30 | 60 | 29 | 29 | 29 | 30 | - | - |

Heat Exchanger Duties, MM Btu/hr

E-1: 7.6
E-2: 3.0
E-4: 1.6
E-5: 2.4

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 2.1 |
| $Na_2CO_3$, | 1.5 |
| $K_2CO_3$, | 2.6 |
| | 6.2 |

## MATERIAL BALANCE

Case No. 6. 400 MW., 6.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 448 | | 22 | | | | | |
| $SO_3$ | #Mol/hr | 50 | | 2 | | | | | |
| HCl | #Mol/hr | 3 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 14200 | 543 | 14800 | | 987 | | 987 | 480 |
| $H_2O$ | #Mol/hr | 10800 | 74 | 10800 | | | | 987 | 480 |
| $O_2$ | #Mol/hr | 3600 | | 3600 | | | | | |
| $N_2$ | #Mol/hr | 81000 | 2591 | 83600 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 60 | | 60 | 60 |
| $H_2S$ | #Mol/hr | | | | | | | | 507 |
| Total | #Mol/hr | 110100 | 3208 | 112800 | | 1047 | | 2034 | 1527 |
| Fly Ash | #/hr | 119.0 | | 6.0 | | | | | |
| Process Gas Input | | | | | | | | | |
| Air | #Mol/hr | | | | 3349 | | | | |
| Water | #Mol/hr | | | | | | 324 | | |
| Steam | #Mol/hr | | | | | | 663 | | |
| Temp. °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 696 | 20.2 | 0.7 | 21.2 | 6.6 | 6.2 | 12.8 | 9.6 |

## MATERIAL BALANCE

Case No. 6, 400 MW, 6.0% Sulfur in Coal.
Coke Rate, 22800 lb/hr

| | | Stream No. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Melt Components** | | 14 | 15 | 17 | 18 | 19 | 23 | 26[1] | 31 | 32 |
| $M_2S$ | #Mol/hr | 0 | 10 | 36 | 10 | 533 | 530 | 27 | 3.1 | 0.0 |
| $M_2SO_3$ | #Mol/hr | 774 | 348 | 348 | 347 | 0 | 0 | 0 | 0.0 | 1.2 |
| $M_2SO_4$ | #Mol/hr | 262 | 158 | 178 | 157 | 21 | 21 | 21 | 0.1 | 0.6 |
| $M_2CO_3$ | #Mol/hr | 2472 | 1236 | 2946 | 1232 | 1192 | 1185 | 1711 | 6.4 | 3.8 |
| KCl, Dissolved | #Mol/hr | 128 | 64 | 128 | 64 | 64 | 64 | 64 | 0.4 | 0.2 |
| Total | | 3636 | 1816 | 3636 | 1810 | 1810 | 1800 | 1823 | 10.0 | 5.8 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 410.9 | 205.4 | 205.4 | 2.0 | 2.0 | 0 | 0 | 2.0 | 203.4 |
| Fly Ash | #/hr | 230.7 | 115.4 | 115.4 | 1.2 | 1.2 | 0 | 0 | 1.2 | 114.2 |
| Coke Residue | #/hr | 18.0 | 9.0 | 18.0 | 0.1 | 882.1 | 8.8 | 8.8 | 873.3 | 8.8 |
| Total | #/hr | 659.6 | 329.8 | 338.8 | 3.3 | 885.3 | 8.8 | 8.8 | 876.5 | 326.4 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 364 | 182 | 364 | 181 | 181 | 180 | 182 | - | - |

Heat Exchanger Duties, MM Btu/hr

| | |
|---|---|
| E-1: | 47.1 |
| E-2: | 18.0 |
| E-4: | 10.0 |
| E-5: | 15.0 |

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 4.4 |
| $Na_2CO_3$, | 3.2 |
| $K_2CO_3$, | 4.0 |
| | 11.6 |

## MATERIAL BALANCE

Case No. 7. 1000 MW, 3.0% Sulfur in Coal.

| | | Stream No. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
| $SO_2$ | #Mol/hr | 560 | | 28 | | | | | |
| $SO_3$ | #Mol/hr | 63 | | 4 | | | | | |
| HCl | #Mol/hr | 7 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 38800 | 679 | 39500 | | 1234 | | 1234 | 600 |
| $H_2O$ | #Mol/hr | 24400 | 92 | 24500 | | | | 1234 | 600 |
| $O_2$ | #Mol/hr | 10500 | | 10400 | | | | | |
| $N_2$ | #Mol/hr | 219500 | 3239 | 222800 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 75 | | 75 | 75 |
| $H_2S$ | #Mol/hr | | | | | | | | 634 |
| Total | #Mol/hr | 293800 | 4010 | 297200 | | 1309 | | 2543 | 1909 |
| Fly Ash | #/hr | 299.2 | | 15.0 | | | | | |
| Process Gas Input | | | | | | | | | |
| Air | #Mol/hr | | | | 4186 | | | | |
| Water | #Mol/hr | | | | | | 405 | | |
| Steam | #Mol/hr | | | | | | 829 | | |
| Temp., $^oF$ | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 1855 | 25.3 | 1878 | 26.4 | 8.3 | 7.8 | 16.1 | 12.1 |

## MATERIAL BALANCE

Case No. 7. 1000 MW, 3.0% Sulfur in Coal.
Coke Rate, 28400 lb/hr

Stream No.

| Melt Components | | 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| $M_2S$ | #Mol/hr | 0 | 12 | 45 | 12 | 671 | 666 | 31 | 3.9 | 0.1 |
| $M_2SO_3$ | #Mol/hr | 968 | 435 | 435 | 432 | 0 | 0 | 0 | 0 | 2.9 |
| $M_2SO_4$ | #Mol/hr | 335 | 204 | 230 | 202 | 26 | 26 | 26 | 0.1 | 1.4 |
| $M_2CO_3$ | #Mol/hr | 3112 | 1556 | 3706 | 1549 | 1498 | 1490 | 2150 | 8.0 | 9.2 |
| KCl, Dissolved | #Mol/hr | 162 | 81 | 161 | 80 | 80 | 80 | 80 | 0.5 | 0.5 |
| Total | | 4577 | 2288 | 4577 | 2275 | 2275 | 2262 | 2287 | 12.5 | 14.1 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 1027.2 | 513.6 | 513.6 | 5.1 | 5.1 | 0 | 0 | 4.5 | 490.8 |
| Fly Ash | #/hr | 576.8 | 288.4 | 288.4 | 2.9 | 2.9 | 0 | 0 | 3.9 | 281.4 |
| Coke Residue | #/hr | 22.5 | 11.2 | 22.5 | 0.1 | 1102.8 | 11.0 | 11.0 | 1089.4 | 11.0 |
| Total | #/hr | 1626.5 | 813.2 | 824.5 | 8.1 | 1110.8 | 11.0 | 11.0 | 1097.8 | 783.2 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 850 | 850 | 850 |
| Nominal Flow rate, gpm | | 458 | 229 | 458 | 228 | 228 | 226 | 229 | - | - |

Heat Exchanger Duties, MM Btu/hr

E-1: 59.2
E-2: 22.4
E-4: 12.5
E-5: 18.8

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 11.0 |
| $Na_2CO_3$, | 8.0 |
| $K_2CO_3$, | 9.9 |
| | 28.9 |

# MATERIAL BALANCE

Case No. 8. 1000 MW, 1.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 177 | | 9 | | | | | |
| $SO_3$ | #Mol/hr | 20 | | 1 | | | | | |
| HCl | #Mol/hr | 7 | | 0 | | | | | |
| $CO_2$ | #Mol/hr | 42400 | 226 | 42600 | | 408 | | 411 | 200 |
| $H_2O$ | #Mol/hr | 9400 | 31 | 9400 | | | | 411 | 200 |
| $O_2$ | #Mol/hr | 9900 | | 9900 | | | | | |
| $N_2$ | #Mol/hr | 223900 | 1080 | 225000 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 25 | | 25 | 25 |
| $H_2S$ | #Mol/hr | | | | | | | | 202 |
| Total | #Mol/hr | 285800 | 1337 | 286900 | | 433 | | 847 | 627 |
| Fly Ash | #/hr | 297.5 | | 14.9 | | | | | |
| Process Gas Input | | | | | | | | | |
| Air | #Mol/hr | | | | 1395 | | | | |
| Water | #Mol/hr | | | | | | 135 | | |
| Steam | #Mol/hr | | | | | | 276 | | |
| Temp., °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 1805 | 8.5 | 1812 | 9.8 | 2.8 | 2.6 | 5.4 | 4.0 |

## MATERIAL BALANCE

Case No. 8. 1000 MW, 1.0% Sulfur in Coal.
Coke Rate, 9500 lb/hr

| | | Stream No. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Melt Components** | | 14 | 15 | 17 | 18 | 19 | 23 | 26[(1)] | 31 | 32 |
| $M_2S$ | #Mol/hr | 0 | 4 | 15 | 4 | 215 | 212 | 10 | 1.2 | 0.1 |
| $M_2SO_3$ | #Mol/hr | 322 | 145 | 145 | 142 | 0 | 0 | 0 | 0 | 2.9 |
| $M_2SO_4$ | #Mol/hr | 102 | 60 | 69 | 60 | 9 | 9 | 9 | 0 | 1.4 |
| $M_2CO_3$ | #Mol/hr | 1019 | 511 | 1220 | 501 | 483 | 482 | 710 | 2.8 | 9.2 |
| KCl, Dissolved | #Mol/hr | 55 | 28 | 55 | 28 | 28 | 28 | 28 | 0.1 | 0.5 |
| Total | | 1498 | 748 | 1504 | 735 | 735 | 731 | 757 | 4.1 | 14.1 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 1027.2 | 513.6 | 513.6 | 5.1 | 5.1 | 0 | 0 | 5.1 | 508.5 |
| Fly Ash | #/hr | 576.8 | 288.4 | 288.4 | 2.9 | 2.9 | 0 | 0 | 2.9 | 285.5 |
| Coke Residue | #/hr | 7.5 | 3.8 | 7.5 | 0.1 | 367.6 | 3.8 | 3.8 | 363.9 | 3.8 |
| Total | #/hr | 1611.5 | 805.8 | 809.5 | 8.1 | 375.6 | 3.8 | 3.8 | 371.9 | 797.8 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 150 | 75 | 150 | 74 | 73 | 73 | 76 | - | - |

Heat Exchanger Duties, MM Btu/hr

E-1: 19.1
E-2: 7.5
E-4: 4.0
E-5: 6.0

(1) Includes Stream 30, #Mol/hr

$Li_2CO_3$, 5.2
$Na_2CO_3$, 3.8
$K_2CO_3$, 6.4
15.4

## MATERIAL BALANCE

Case No. 9. 1000 MW, 5.0% Sulfur in Coal.

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 1120 | | 56 | | | | | |
| $SO_3$ | #Mol/hr | 124 | | 6 | | | | | |
| HCl | #Mol/hr | 7 | | 1 | | | | | |
| $CO_2$ | #Mol/hr | 35600 | 1358 | 37000 | | 2468 | | 2468 | 1200 |
| $H_2O$ | #Mol/hr | 26900 | 185 | 27100 | | | | 2468 | 1200 |
| $O_2$ | #Mol/hr | 9000 | | 9000 | | | | | |
| $N_2$ | #Mol/hr | 202500 | 6478 | 209000 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 150 | | 150 | 150 |
| $H_2S$ | #Mol/hr | | | | | | | | 1268 |
| Total | #Mol/hr | 275300 | 8021 | 282200 | | 2618 | | 5086 | 3818 |
| Fly Ash | #/hr | 297.5 | | 14.9 | | | | | |
| **Process Gas Input** | | | | | | | | | |
| Air | #Mol/hr | | | | 8372 | | | | |
| Water | #Mol/hr | | | | | | 810 | | |
| Steam | #Mol/hr | | | | | | 1658 | | |
| Temp. °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 1740 | 50.6 | 1.8 | 52.9 | 16.6 | 15.6 | 32.1 | 24.1 |

## MATERIAL BALANCE

Case No. 9. 1000 MW, 6.0% Sulfur in Coal.
Coke Rate, 56900 lb/hr

Stream No.

| Melt Components | | 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| $M_2S$ | #Mol/hr | 0 | 24 | 90 | 24 | 1332 | 1325 | 66 | 7.8 | 0.1 |
| $M_2SO_3$ | #Mol/hr | 1934 | 870 | 870 | 868 | 0 | 0 | 0 | 0.0 | 3.0 |
| $M_2SO_4$ | #Mol/hr | 655 | 394 | 446 | 392 | 52 | 52 | 52 | 0.2 | 1.4 |
| $M_2CO_3$ | #Mol/hr | 6180 | 3090 | 7368 | 3080 | 2979 | 2962 | 4278 | 16.0 | 9.5 |
| KCl,Dissolved | #Mol/hr | 320 | 160 | 320 | 160 | 160 | 159 | 159 | 1.0 | 0.5 |
| Total | | 9089 | 4538 | 9094 | 4524 | 4523 | 4498 | 4555 | 25.0 | 14.5 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | 1027.2 | 513.6 | 513.6 | 5.1 | 5.1 | 0 | 0 | 5.1 | 508.5 |
| Fly Ash | #/hr | 576.8 | 288.4 | 288.4 | 2.9 | 2.9 | 0 | 0 | 2.9 | 285.5 |
| Coke Residue | #/hr | 45.0 | 22.5 | 45.0 | 0.2 | 2205.2 | 22.0 | 22.0 | 2183.2 | 22.2 |
| Total | #/hr | 1649.0 | 824.5 | 847.0 | 8.2 | 2213.2 | 22.0 | 22.0 | 2191.2 | 816.2 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 909 | 454 | 909 | 452 | 452 | 450 | 456 | - | - |

Heat Exchanger Duties, MM Btu/hr

E-1: 7.6
E-2: 45.0
E-4: 25.0
E-5: 37.5

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 11.0 |
| $Na_2CO_3$, | 8.0 |
| $K_2CO_3$, | 9.9 |
| | 28.9 |

MATERIAL BALANCE

Case No. 10. Copper Smelter, Reverberatory Furnace - 200 T/D Copper

Stream No.

| Process Gas | | 2 | 4 | 5 | 6 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | #Mol/hr | 117 | | 6 | | | | | |
| $SO_3$ | #Mol/hr | 13 | | 1 | | | | | |
| HCl | #Mol/hr | | | | | | | | |
| $CO_2$ | #Mol/hr | 1100 | 142 | 1200 | | 258 | | 258 | 126 |
| $H_2O$ | #Mol/hr | 300 | 19 | 300 | | | | 258 | 126 |
| $O_2$ | #Mol/hr | 300 | | 300 | | | | | |
| $N_2$ | #Mol/hr | 5200 | 677 | 5900 | | | | | |
| Coke Volatiles | #Mol/hr | | | | | 16 | | 16 | 16 |
| $H_2S$ | #Mol/hr | | | | | | | | 132 |
| Total | #Mol/hr | 7000 | 838 | 7700 | | 274 | | 532 | 400 |
| Fly Ash | #/hr | 10.0 | | 0.5 | | | | | |
| Process Gas Input | | | | | | | | | |
| Air | #Mol/hr | | | | 913 | | | | |
| Water | #Mol/hr | | | | | | 85 | | |
| Steam | #Mol/hr | | | | | | 174 | | |
| Temp., °F | | 850 | 850-1120 | 850 | 60 | 850 | 850 | 850 | 850 |
| Flow, M SCFM | | 44.2 | 5.3 | 48.7 | 5.8 | 1.7 | 1.6 | 3.4 | 2.5 |

## MATERIAL BALANCE

Case No. 10. Copper Smelter, Reverberatory Furnace - 200 T/D Copper.
Coke Rate, 5900 lb/hr.

Stream No.

| Melt Components | | 14 | 15 | 17 | 18 | 19 | 23 | 26(1) | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| $M_2S$ | #Mol/hr | 0 | 2 | 9 | 2 | 139 | 138 | 7 | 0.8 | 0.0 |
| $M_2SO_3$ | #Mol/hr | 202 | 91 | 91 | 91 | 0 | 0 | 0 | 0.0 | 0.0 |
| $M_2SO_4$ | #Mol/hr | 68 | 41 | 46 | 41 | 5 | 5 | 5 | 0.0 | 0.0 |
| $M_2CO_3$ | #Mol/hr | 573 | 287 | 697 | 287 | 277 | 275 | 410 | 1.7 | 0.1 |
| KCl, Dissolved | #Mol/hr | | | | | | | | | |
| Total | | 843 | 421 | 843 | 421 | 421 | 418 | 422 | 2.5 | 0.1 |
| **Solids** | | | | | | | | | | |
| KCl | #/hr | | | | | | | | | |
| Fly Ash | #/hr | 19.0 | 9.5 | 9.5 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 9.4 |
| Coke Residue | #/hr | 4.6 | 2.3 | 4.6 | 0.0 | 230.4 | 2.3 | 2.3 | 228.1 | 2.3 |
| Total | #/hr | 23.6 | 11.8 | 14.1 | 0.1 | 230.5 | 2.3 | 2.3 | 228.2 | 11.7 |
| Temp., °F | | 850 | 850 | 850 | 850 | 1500 | 850 | 930 | 850 | 850 |
| Nominal Flow rate, gpm | | 84 | 42 | 84 | 42 | 42 | 42 | 42 | - | - |

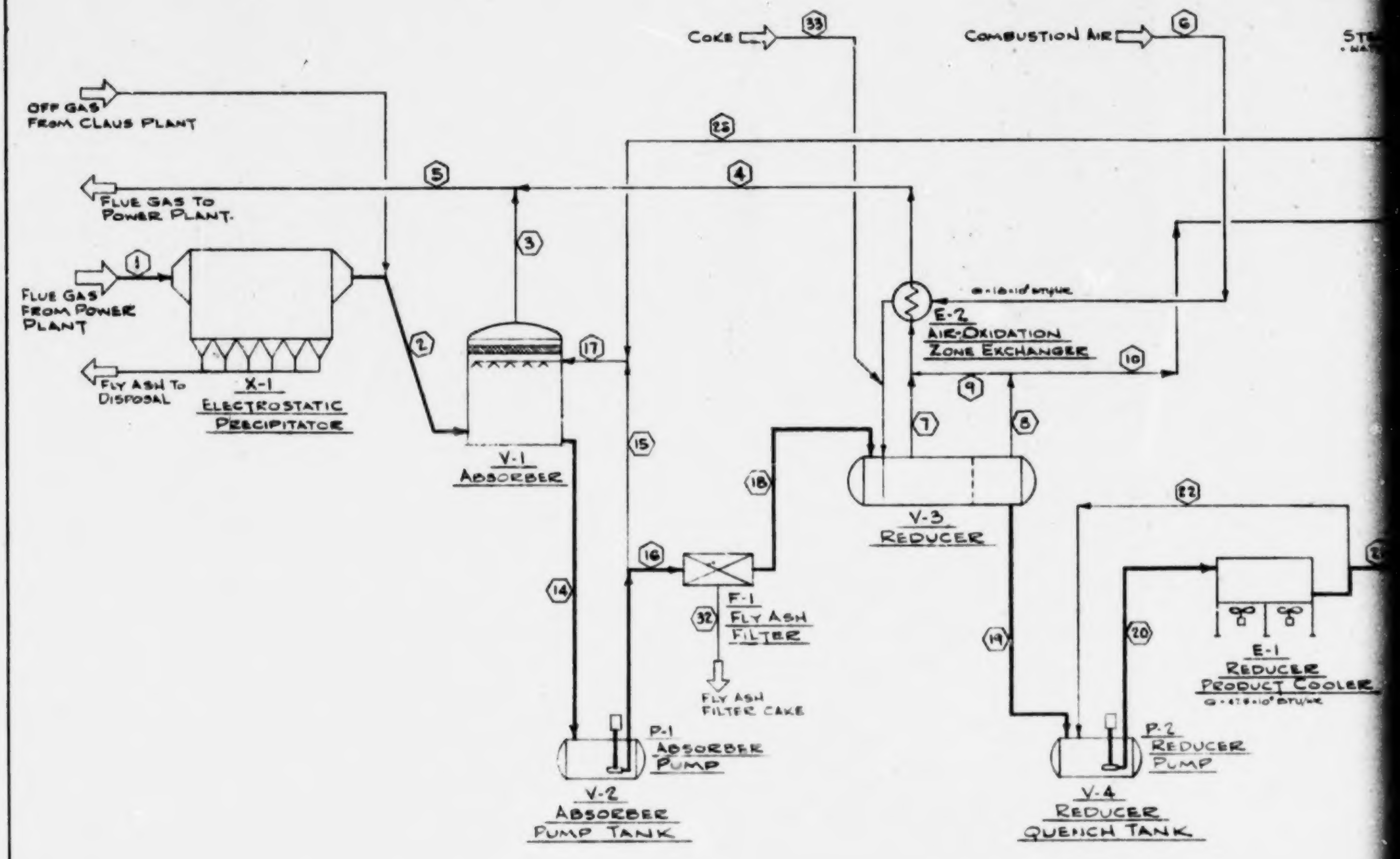
Heat Exchanger Duties, MM Btu/hr

| | |
|---|---|
| E-1: | 11.0 |
| E-2: | 4.7 |
| E-4: | 2.6 |
| E-5: | 3.9 |

(1) Includes Stream 30, #Mol/hr

| | |
|---|---|
| $Li_2CO_3$, | 0.8 |
| $Na_2CO_3$, | 0.6 |
| $K_2CO_3$, | 0.4 |
| | 1.8 |

A


COKE
33
COMBUSTION AIR
6
STE
OFF GAS FROM CLAUS PLANT
25
5
4
FLUE GAS TO POWER PLANT.
3
1
FLUE GAS FROM POWER PLANT
FLY ASH TO DISPOSAL
X-1 ELECTROSTATIC PRECIPITATOR
2
17
V-1 ABSORBER
E-2 AIR-OXIDATION ZONE EXCHANGER
Q = 18×10⁶ BTU/HR
10
9
7
8
15
18
V-3 REDUCER
22
16
F-1 FLY ASH FILTER
32
FLY ASH FILTER CAKE
14
19
20
E-1 REDUCER PRODUCT COOLER
Q = 47.8×10⁶ BTU/HR
P-1 ABSORBER PUMP
V-2 ABSORBER PUMP TANK
P-2 REDUCER PUMP
V-4 REDUCER QUENCH TANK

| STREAM | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | REGENERATOR | | | |
| | FLUE GAS POWER PLANT | FLUE GAS PPT EXIT | FLUE GAS ABSORBER EXIT | REDUCER EXIT TOTAL RETURN | FLUE GAS RETURN POWER PLANT | REDUCER INPUT AIR OXIDATION ZONE | REDUCER EXIT OXIDATION ZONE | REDUCER EXIT REDUCTION ZONE | REDUCER EXIT REDUCTION ZONE FILTER | INPUT PROCESS GAS | INPUT WATER AND STEAM | INPUT TOTAL | EXIT TO CLAUS PLANT |
| PROCESS GAS | | | | | | 5549 | | | | | STEAM 695 | | |
| $SO_2$ #MOL/HR | 446.0 | 446.0 | 22.4 | | 22.4 | | | | | | | | |
| $SO_3$ #MOL/HR | 90.4 | 90.4 | 5.1 | | 5.1 | | | | | | | | |
| HCl #MOL/HR | 9.6 | 9.6 | 0.5 | | 0.5 | | | | | | | | |
| $CO_2$ #MOL/HR | 51000 | 51000 | 51000 | 845 | 51600 | | 562 | 1168 | 161 | 987 | | 987 | 480 |
| $H_2O$ #MOL/HR | 19500 | 19500 | 19500 | 74 | 19600 | | 74 | | | | WATER 864 | 987 | 480 |
| $O_2$ #MOL/HR | 8400 | 8400 | 8300 | | 8300 | | | | | | | | |
| $N_2$ #MOL/HR | 179600 | 179600 | 179600 | 2591 | 178800 | | 2591 | | | | | | |
| COKE VOLATILES #MOL/HR | | | | | | | | 70 | 10 | 60 | | 60 | 60 |
| $H_2S$ #MOL/HR | | | | | | | | | | | | | 907 |
| TOTAL #MOL/HR | 259000 | 259000 | 254800 | 3506 | 257700 | 5549 | 5087 | 1256 | 191 | 1047 | 987 | 2034 | 1927 |
| FLYASH #/HR | 46000 | 2394 | 12.0 | | 12.0 | | | | | | | | |
| TEMP °F | 650 | 650 | 230 | 850-1150 | 230 | 60 | 1900 | 1900 | 1300 | 850 | 850 | 850 | 850 |
| FLOW SCFM | 1.664×10⁵ | 1.484×10⁵ | 1.481×10⁵ | 20265 | 1.502×10⁵ | 21196 | 19122 | 7821 | 1207 | 6614 | 6235 | 12849 | 9446 |

| STREAM | 14 | 4 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|
| | ABSORBER EXIT | ABSORBER EXIT DISPROPORTIONATION | ABSORBER RECYCLE | FLYASH FILTER INLET | ABSORBER INLET | REDUCER INLET | REDUCER EXIT | REDUCER PRODUCT COOLER INLET | COKE FILTE |
| MELT COMPONENTS | | | | | | | | | |
| $M_2S$ #MOL/HR | 0 | 19 | 10 | 0 | 56 | 10 | 557 | | |
| $M_2SO_3$ #MOL/HR | 774 | 496 | 548 | 548 | 548 | 546 | 04 | | |
| $M_2SO_4$ #MOL/HR | 268 | 527 | 65 | 65 | 184 | 66 | 61 | | 61 |
| $M_2CO_3$ #MOL/HR | 2490 | 2490 | 1245 | 1245 | 2965 | 250 | 1198 | | |
| KCl #MOL/HR | 150 | 150 | 69 | 69 | 129 | 64 | 64 | | 64 |
| TOTAL | 3662 | 3662 | 1851 | 1851 | 3662 | 820 | 1820 | 11850 | |
| SOLIDS | | | | | | | | | |
| KCl #/HR | 8218 | 8218 | 4109 | 4109 | 4109 | 41 | 41 | | |
| FLYASH #/HR | 4614 | 4614 | 2307 | 2307 | 2307 | 2.6 | 2.3 | | |
| COKE RESIDUE #/HR | 18.0 | 18.0 | 9.0 | 9.0 | 18.0 | 0.1 | NOTE 2 | | |
| TOTAL #/HR | 13012 | 13012 | 6506 | 6506 | 6506 | 45 | 666.6 | | |
| TEMP °F | 850 | 850 | 850 | 850 | 850 | 850 | 1900 | 350 | 850 |
| NORMAL FLOW RATE GPM | 366 | 366 | 183 | 183 | 366 | 182 | 182 | 1185 | 182 |

| MK | DATE | REVISIONS | DR. CH. | APP | MK | DATE | REVISIONS | DR. CH. | APP | NUMBER | REFERENCE DRAWINGS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 8-10 | ISSUED FOR INFORMATION | P.C. | | | | | | | | |

B

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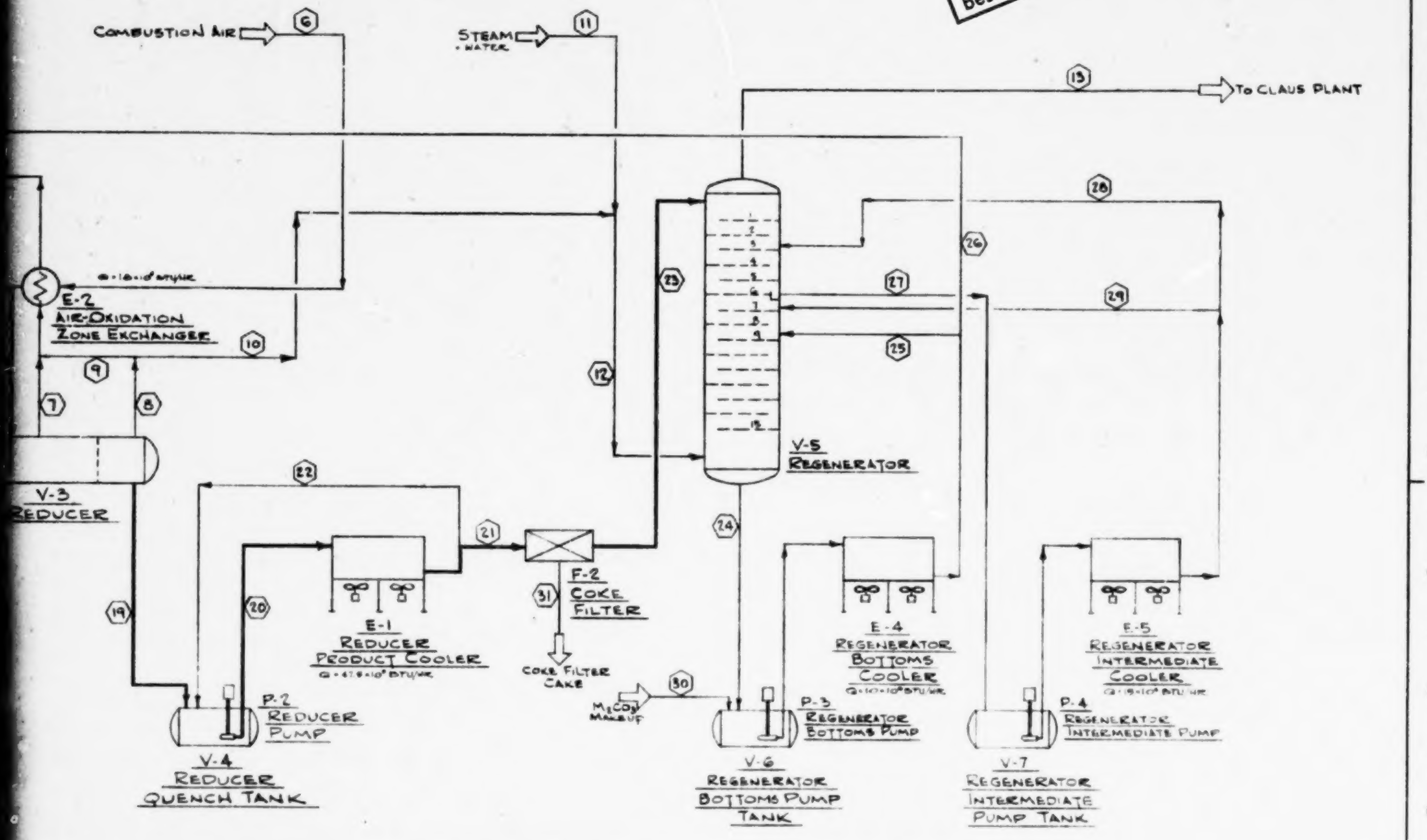
COMBUSTION AIR
6
STEAM
+ WATER
11
13
TO CLAUS PLANT
28
26
27
29
25
23
12
10
9
7
8
E-2
AIR-OXIDATION
ZONE EXCHANGER
Q = 10×10⁶ BTU/HR
V-3
REDUCER
22
21
19
20
V-5
REGENERATOR
24
E-1
REDUCER
PRODUCT COOLER
Q = 47.9×10⁶ BTU/HR
F-2
COKE
FILTER
31
COKE FILTER
CAKE
M₂CO₃
MAKEUP
30
E-4
REGENERATOR
BOTTOMS
COOLER
Q = 10×10⁶ BTU/HR
E-5
REGENERATOR
INTERMEDIATE
COOLER
Q = 15×10⁶ BTU/HR
P-2
REDUCER
PUMP
P-3
REGENERATOR
BOTTOMS PUMP
P-4
REGENERATOR
INTERMEDIATE PUMP
V-4
REDUCER
QUENCH TANK
V-6
REGENERATOR
BOTTOMS PUMP
TANK
V-7
REGENERATOR
INTERMEDIATE
PUMP TANK
1
2
3
4
5
6
7
8
9
12

| 14 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | REGENERATOR | | | | | | | | | | |
| ABSORBER EXIT | ABSORBER EXIT DISPROPORTIONATION | ABSORBER RECYCLE | FLYASH FILTER INLET | ABSORBER INLET | REDUCER INLET | REDUCER EXIT | REDUCER PRODUCT COOLER INLET | COKE FILTER INLET | REDUCER COOLING STREAM RECYCLE | INLET | EXIT | BOTTOMS RECYCLE | PROCESS RETURN | INTERMEDIATE EXIT | INTERMEDIATE RECYCLE | INTERMEDIATE RETURN | CARBONATE MAKE UP | COKE FILTER CAKE | FLYASH FILTER CAKE | COKE REDUCER INPUT |
| 0 | 19 | 10 | 10 | 56 | 10 | 557 | | 557 | | 555 | | | 25 | | | | | 51 | 01 | |
| 774 | 696 | 546 | 546 | 548 | 546 | 09 | | 06 | | 102 | | | 00 | | | | | 00 | 25 | |
| 268 | 527 | 165 | 65 | 184 | 162 | 81 | | 81 | | 81 | | | 2 | | | | | 01 | 11 | |
| 2490 | 2490 | 1249 | 249 | 2965 | 1258 | 1198 | | 1198 | | 1192 | | | 1780 | | | | $Li_2CO_3$ 6.0 | 64 | 74 | |
| 150 | 150 | 69 | 69 | 129 | 64 | 64 | | 64 | | 64 | | | 64 | | | | $Na_2CO_3$ 4.5<br>$K_2CO_3$ 6.5 | 04 | 04 | |
| 3662 | 3662 | 1851 | 1851 | 3662 | 820 | 1820 | 11630 | 1820 | 10010 | 1810 | 3043 | 1212 | 1851 | 5799 | 1810 | 1989 | 16.5 | 10.0 | 11.5 | |
| | | | | | | | | | | | | | | | | | | | | 22784 |
| 8218 | 8218 | 4109 | 4109 | 4109 | 41 | 41 | | 41 | | 00 | | | 00 | | | | | 56 | 592.6 | |
| 4614 | 4614 | 2507 | 2507 | 2507 | 23 | 23 | | 23 | | 00 | | | 00 | | | | | 51 | 2291 | |
| 180 | 180 | 90 | 90 | 180 | 01 | 882.2 | | 882.2 | | 88 | | | 88 | | | | | 871.5 | 88 | |
| 13012 | 13012 | 6906 | 6906 | 6996 | 65 | 888.6 | | 888.6 | | 88 | | | 88 | | | | (1759) | 877.2 | 6855 | |
| 850 | 850 | 850 | 850 | 850 | 850 | 1900 | 1150 | 850 | 850 | 850 | 950 | 850 | 850 | 950 | 850 | 850 | 30 | 850 | 850 | |
| 366 | 366 | 186 | 187 | 366 | 182 | 182 | 1166 | 182 | 1001 | 181 | 304 | 121 | 185 | 560 | 181 | 199 | — | — | — | |

| DRAWING NUMBER | REV |
|---|---|
| F6 218-0001 | 0 |

| DR. CH. | APP. | NUMBER | REFERENCE DRAWINGS |
|---|---|---|---|

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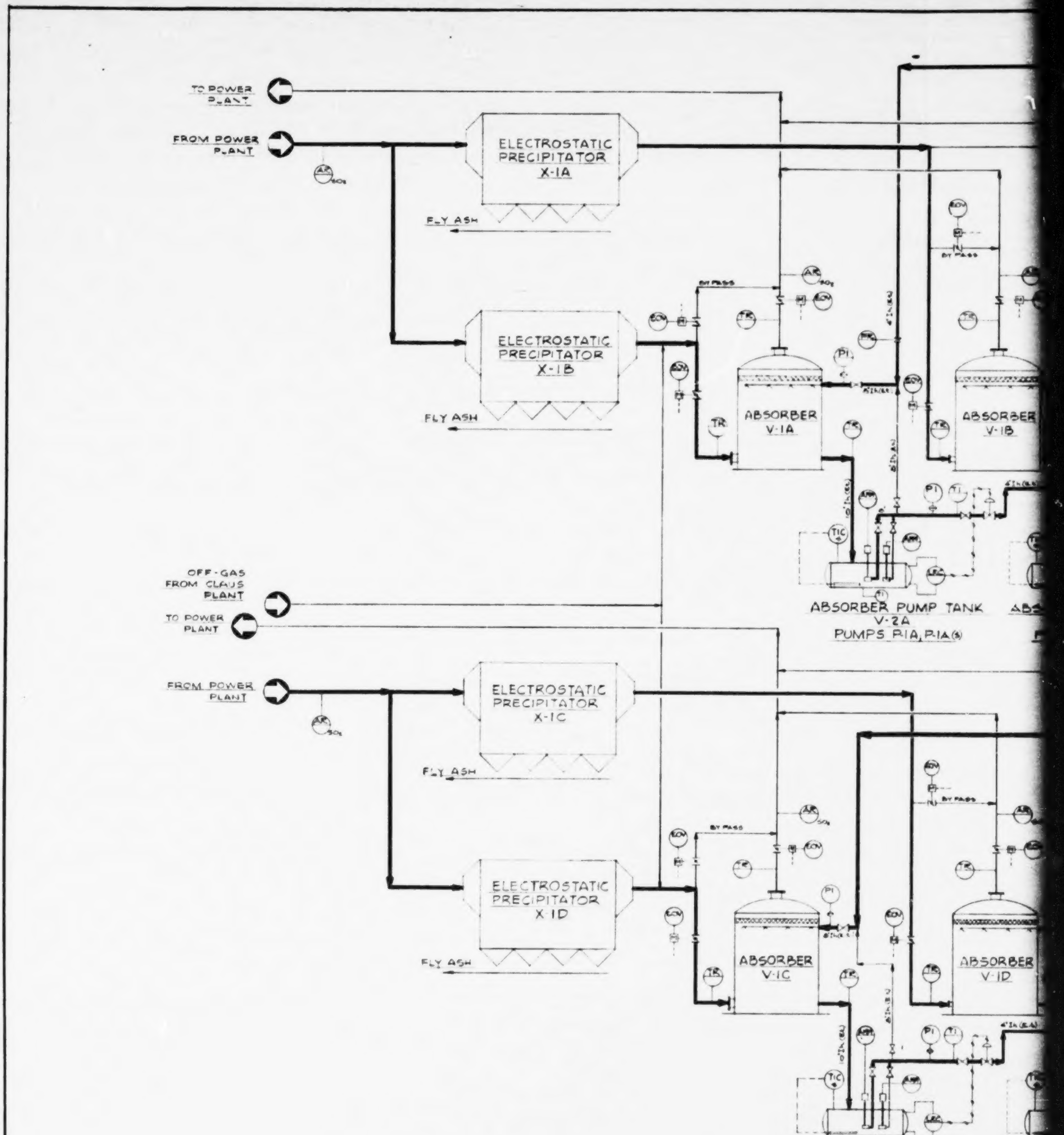
NATIONAL AIR POLLUTION
CONTROL ADMINISTRATION

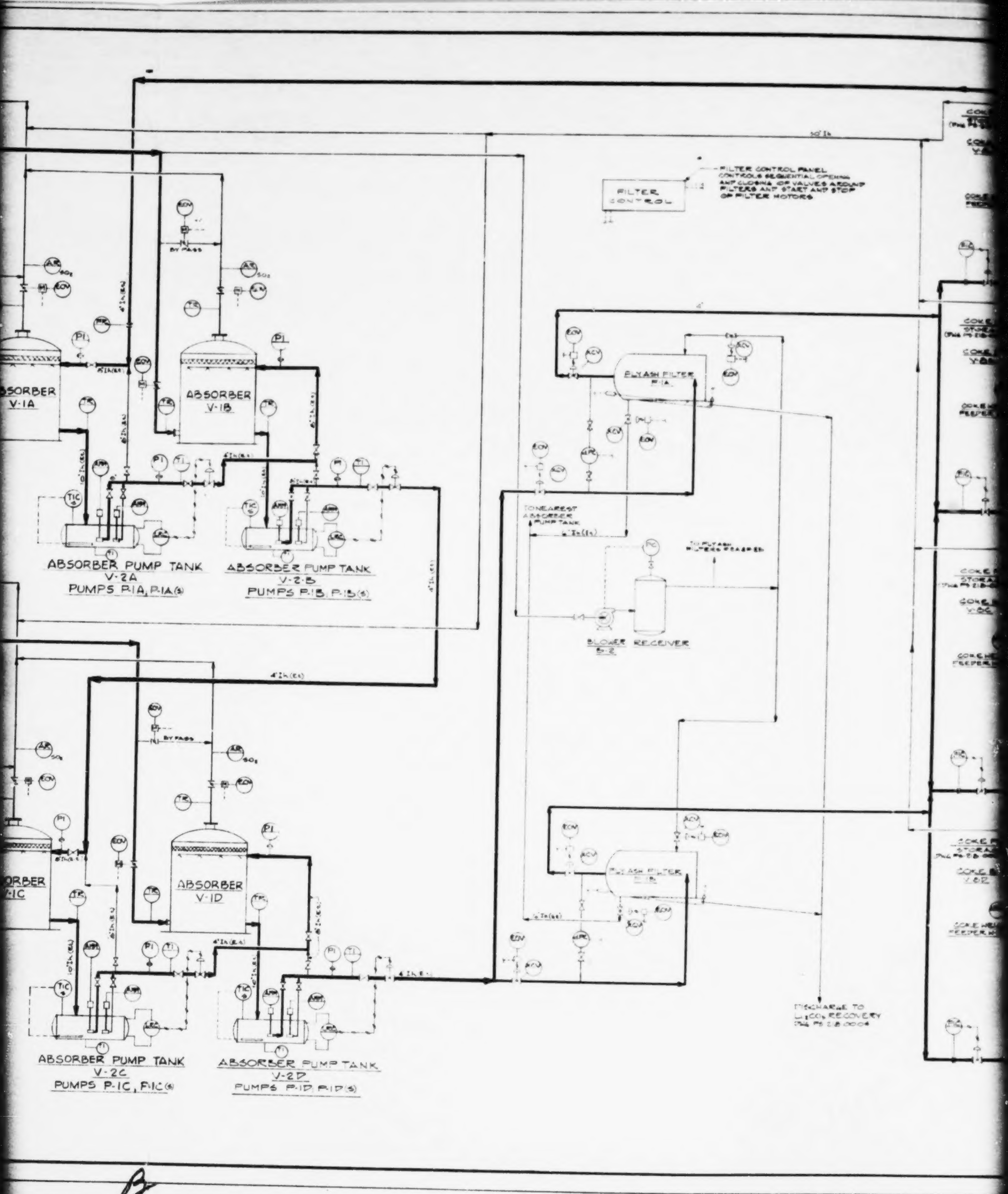
ATOMICS INTERNATIONAL
MOLTEN CARBONATE PROCESS

PROCESS FLOW
DIAGRAM

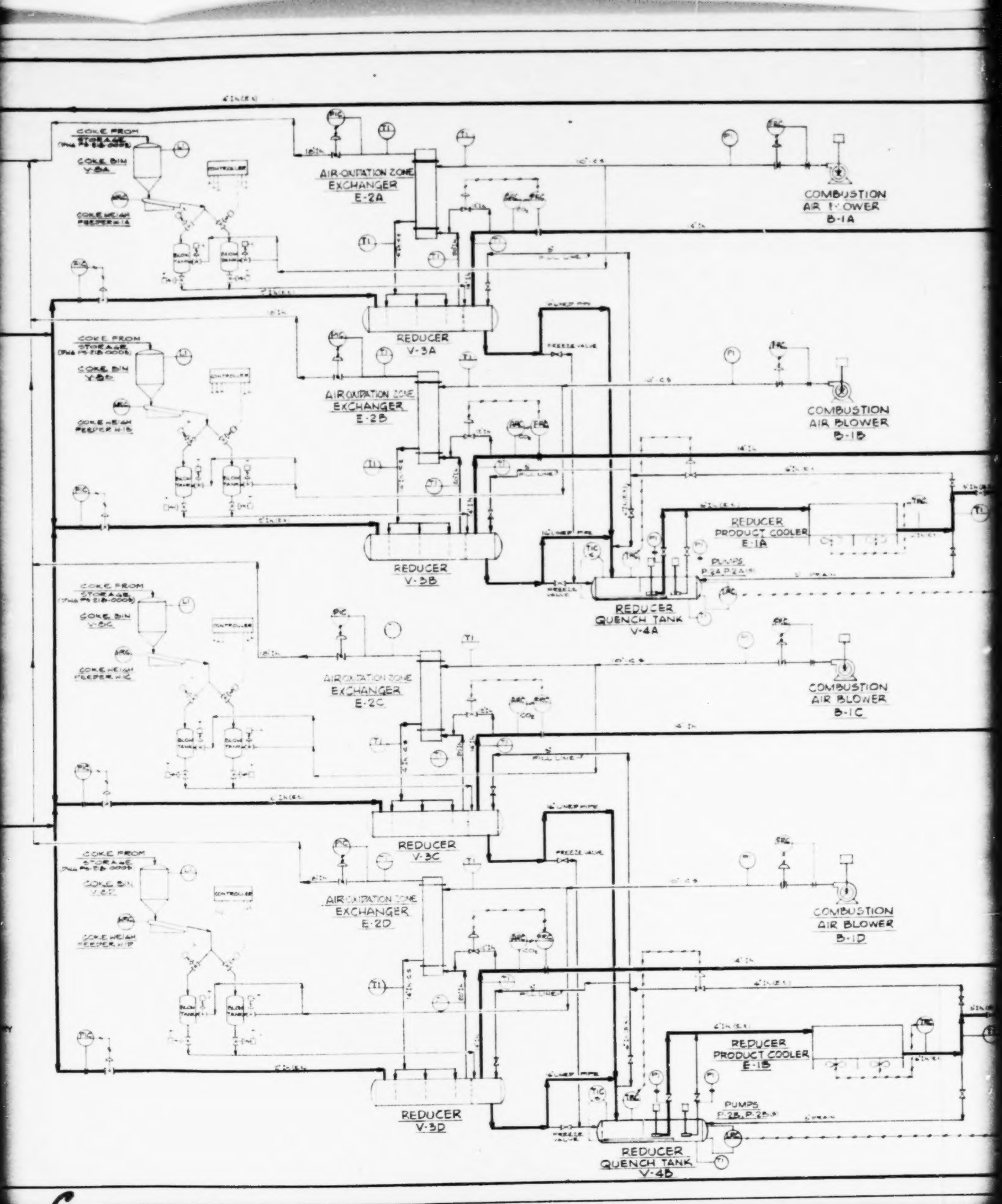
| DR BY | S & B APPROVAL | DATE | DWG NO | REV |
|---|---|---|---|---|
| CH BY | D. P. W. | 11/1/70 | F5 218-0001 | 0 |
| SCALE | CLIENT APPROVAL | DATE | | |

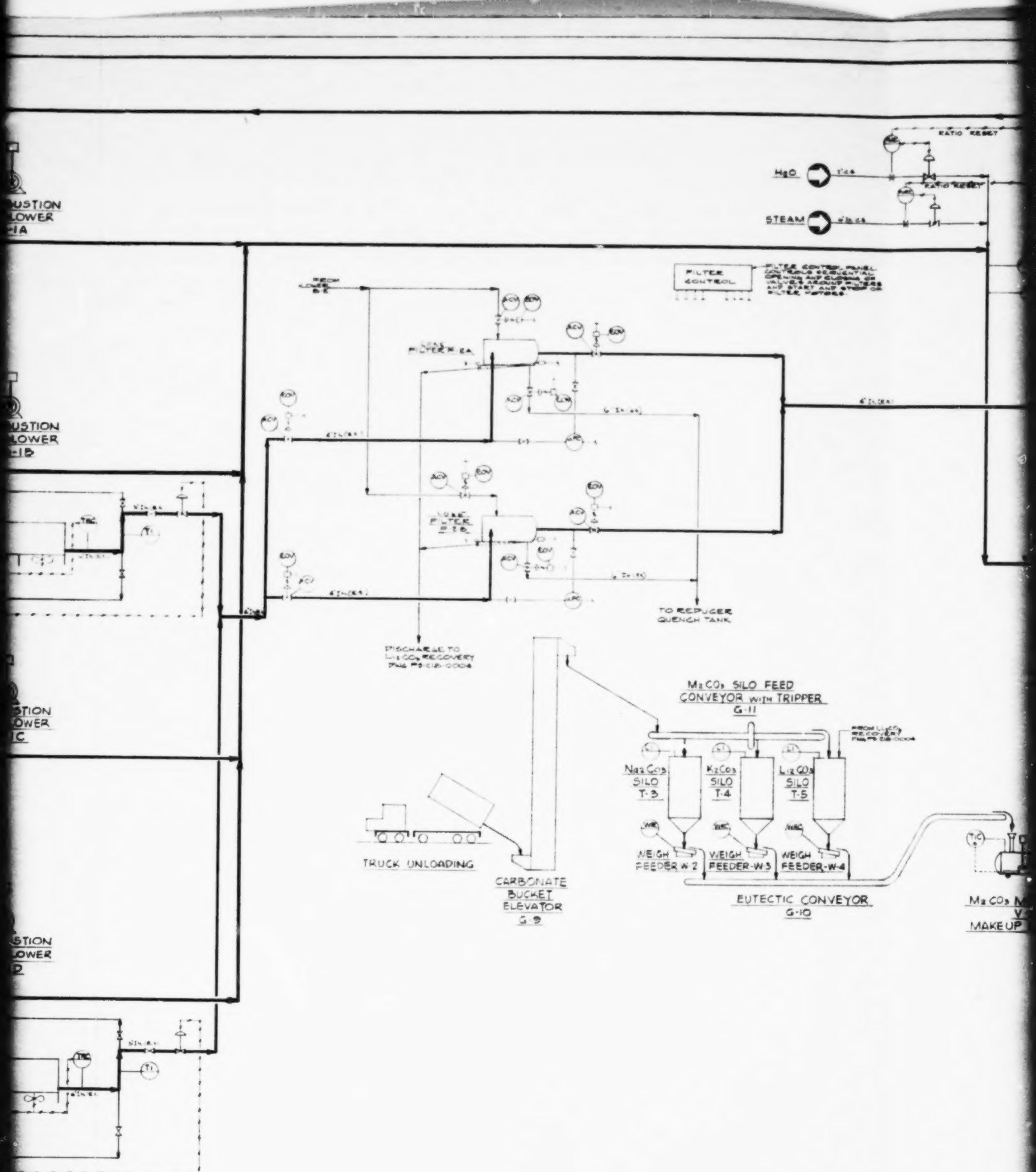

TO POWER PLANT
FROM POWER PLANT
AR SO2
ELECTROSTATIC PRECIPITATOR X-1A
FLY ASH
ELECTROSTATIC PRECIPITATOR X-1B
FLY ASH
BY PASS
EOV
TR
PI
ABSORBER V-1A
ABSORBER V-1B
TIC
LRC
ABSORBER PUMP TANK V-2A PUMPS P-1A, P-1A(S)
OFF-GAS FROM CLAUS PLANT
TO POWER PLANT
FROM POWER PLANT
AR SO2
ELECTROSTATIC PRECIPITATOR X-1C
FLY ASH
ELECTROSTATIC PRECIPITATOR X-1D
FLY ASH
BY PASS
ABSORBER V-1C
ABSORBER V-1D
ABSORBER PUMP TANK V-2C PUMPS P-1C, P-1C(S)

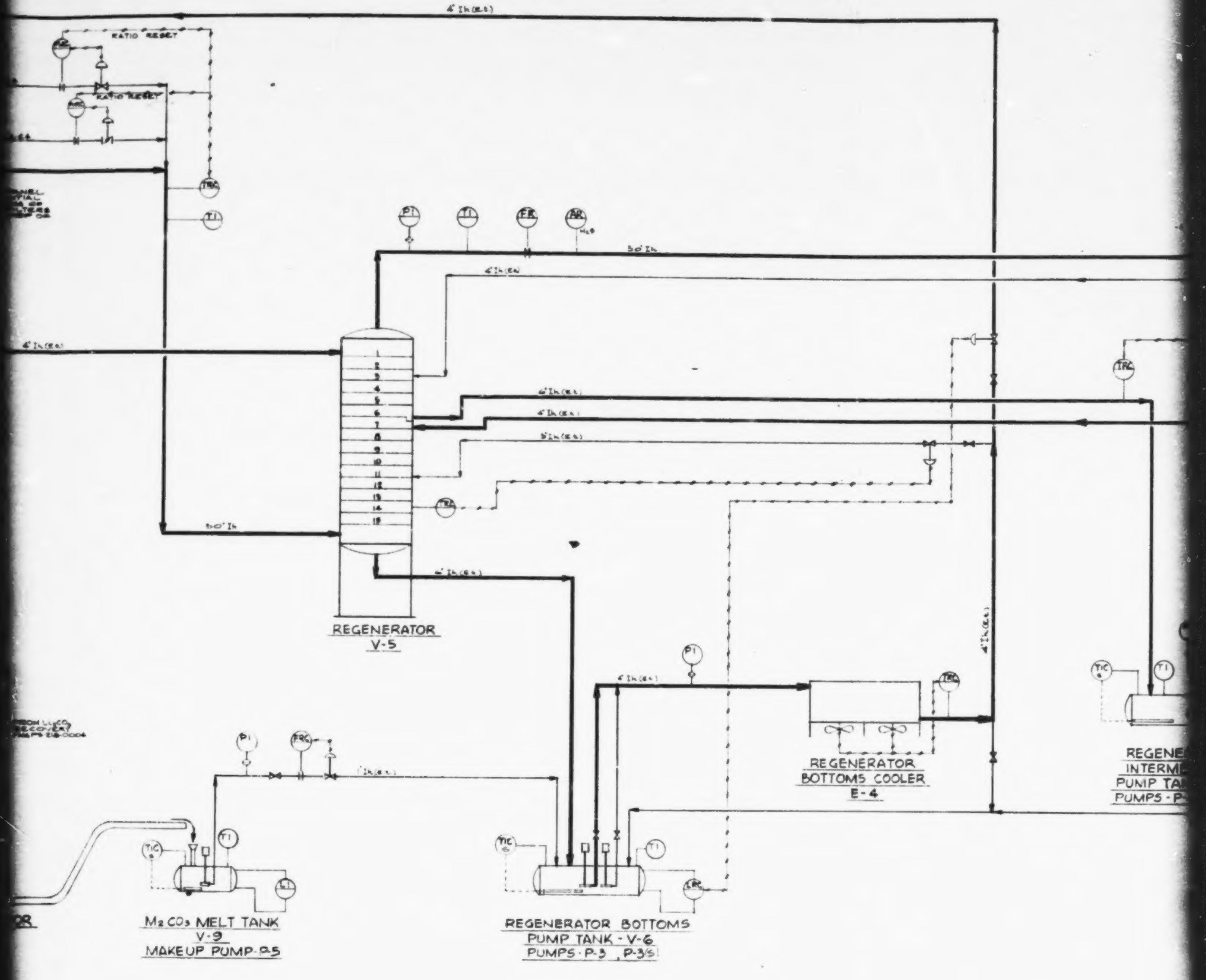
A



ABSORBER V-1A
ABSORBER V-1B
ABSORBER V-1C
ABSORBER V-1D
ABSORBER PUMP TANK V-2A
PUMPS P-1A, P-1A(S)
ABSORBER PUMP TANK V-2B
PUMPS P-1B, P-1B(S)
ABSORBER PUMP TANK V-2C
PUMPS P-1C, P-1C(S)
ABSORBER PUMP TANK V-2D
PUMPS P-1D, P-1D(S)
BY PASS
AR SO2
EOV
PI
TI
TIC
TR
LRC
FILTER CONTROL
FILTER CONTROL PANEL CONTROLS SEQUENTIAL OPENING AND CLOSING OF VALVES AROUND FILTERS AND START AND STOP OF FILTER MOTORS
FLYASH FILTER F-1A
FLYASH FILTER F-1B
ACV
TO NEAREST ABSORBER PUMP TANK
TO FLYASH FILTERS FEASPED
BLOWER B-2
RECEIVER
PC
DISCHARGE TO Li2CO3 RECOVERY DWG FS 2.8.0004
COKE
STORAGE
COKE FEEDER
V-8A
V-8C
V-8D
4" In (Es)
10" In
B


COKE FROM STORAGE
COKE BIN V-8A
COKE WEIGH FEEDER W-1A
CONTROLLER
BLOW TANK
AIR-OXIDATION ZONE EXCHANGER E-2A
REDUCER V-3A
COMBUSTION AIR BLOWER B-1A
FILL LINE
COKE FROM STORAGE
COKE BIN V-8B
COKE WEIGH FEEDER W-1B
AIR OXIDATION ZONE EXCHANGER E-2B
REDUCER V-3B
COMBUSTION AIR BLOWER B-1B
FREEZE VALVE
REDUCER PRODUCT COOLER E-1A
PUMPS P-2A, P-2A(S)
REDUCER QUENCH TANK V-4A
COKE FROM STORAGE
COKE BIN V-8C
COKE WEIGH FEEDER W-1C
AIR OXIDATION ZONE EXCHANGER E-2C
REDUCER V-3C
COMBUSTION AIR BLOWER B-1C
COKE FROM STORAGE
COKE BIN V-8D
COKE WEIGH FEEDER W-1D
AIR OXIDATION ZONE EXCHANGER E-2D
REDUCER V-3D
COMBUSTION AIR BLOWER B-1D
REDUCER PRODUCT COOLER E-1B
PUMPS P-2B, P-2B(S)
REDUCER QUENCH TANK V-4B
PIC
TI
PI
FRC
ARC
LI
TIC
TRC
LRC
CO2
C


USTION
LOWER
-1A
USTION
LOWER
-1B
STION
LOWER
C
STION
LOWER
D
H₂O
STEAM
RATIO RESET
RATIO RESET
FILTER CONTROL
FILTER CONTROL PANEL CONTROLS SEQUENTIAL OPENING AND CLOSING OF VALVES AROUND FILTERS AND START AND STOP OF FILTER MOTORS.
FROM BLOWER B-E
ACV
EOV
LOAD FILTER # 2A
LOAD FILTER # 2B
TO REDUCER QUENCH TANK
DISCHARGE TO Li₂CO₃ RECOVERY DWG F3-218-0004
M₂CO₃ SILO FEED CONVEYOR WITH TRIPPER G-11
FROM Li₂CO₃ RECOVERY DWG F3-218-0004
Na₂CO₃ SILO T-3
K₂CO₃ SILO T-4
Li₂CO₃ SILO T-5
LI
WRC
WEIGH FEEDER W-2
WEIGH FEEDER W-3
WEIGH FEEDER W-4
TRUCK UNLOADING
CARBONATE BUCKET ELEVATOR G-9
EUTECTIC CONVEYOR G-10
TIC
TRC
TI
M₂CO₃ M
V
MAKEUP
D


4" In (E.C.)
RATIO RESET
RATIO RESET
TRC
TI
PI
TI
FR
AR
$H_2O$
50" In
4" In (E.N)
4" In (E.C.)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
6" In (E.C.)
4" In (E.C.)
3" In (E.C.)
TRC
50" In
4" In (E.C.)
TRC
REGENERATOR
V-5
PI
FRC
1" In (E.C.)
PI
6" In (E.C.)
TRC
4" In (E.C.)
TIC
TI
TIC
TI
LI
TIC
TI
LRC
TIC
TI
M₂CO₃ MELT TANK
V-9
MAKEUP PUMP-P-5
REGENERATOR BOTTOMS
PUMP TANK - V-6
PUMPS - P-3 , P-3/S
REGENERATOR
BOTTOMS COOLER
E-4
REGENE
INTERM
PUMP TA
PUMPS - P
OR

E

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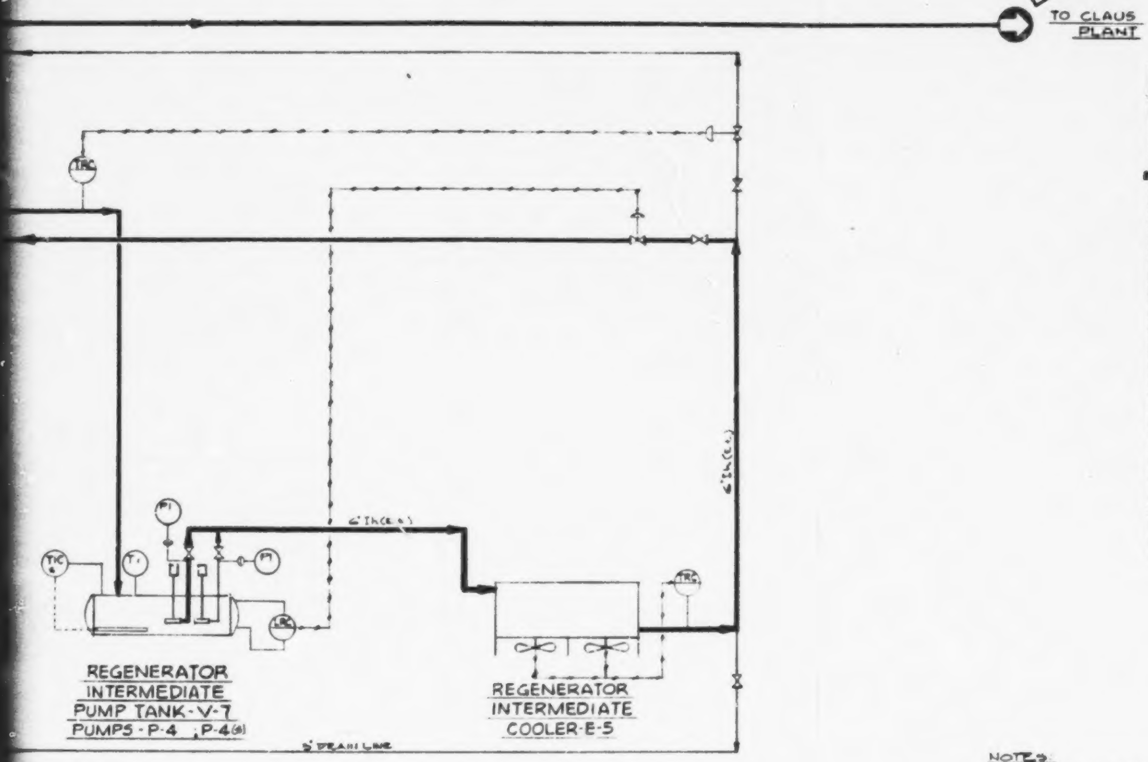
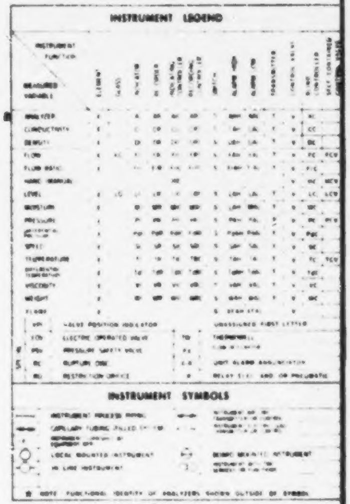

TO CLAUS PLANT
TRC
TIC
TI
PI
PI
LRC
TRC
6" Ih(E.C.)
6" Ih(E.C.)
REGENERATOR INTERMEDIATE PUMP TANK-V-7
PUMPS-P-4 ; P-4(B)
REGENERATOR INTERMEDIATE COOLER-E-5
3" DRAIN LINE


INSTRUMENT LEGEND
INSTRUMENT SYMBOLS

NOTES:

1 · SYMBOLS USED AFTER PIPE SIZE SIGNIFIES THE FOLLOWING
Ih(E.C.) · INSULATION WITH ELECTRICAL TRACING
Ih INSULATION ONLY
C.S · CARBON STEEL PIPE

2 · WHERE NO MATERIAL SPECIFICATION IS DESIGNATED TYPE 347SS SHALL BE USED.

| DRAWING NUMBER | REV |
|---|---|
| PS-218-0002 | 0 |

NATIONAL AIR POLLUTION
CONTROL ADMINISTRATION

ATOMICS INTERNATIONAL
MOLTEN CARBONATE PROCESS

ENGINEERING FLOW DIAGRAM
$SO_x$ REMOVAL

SINGMASTER & BREYER
METALLURGISTS & CHEMICAL ENGINEERS, NEW YORK

| | | | | |
|---|---|---|---|---|
| DR BY | S & B APPROVAL D.R.W. | DATE | DWG NO PS-218-0002 | REV 0 |
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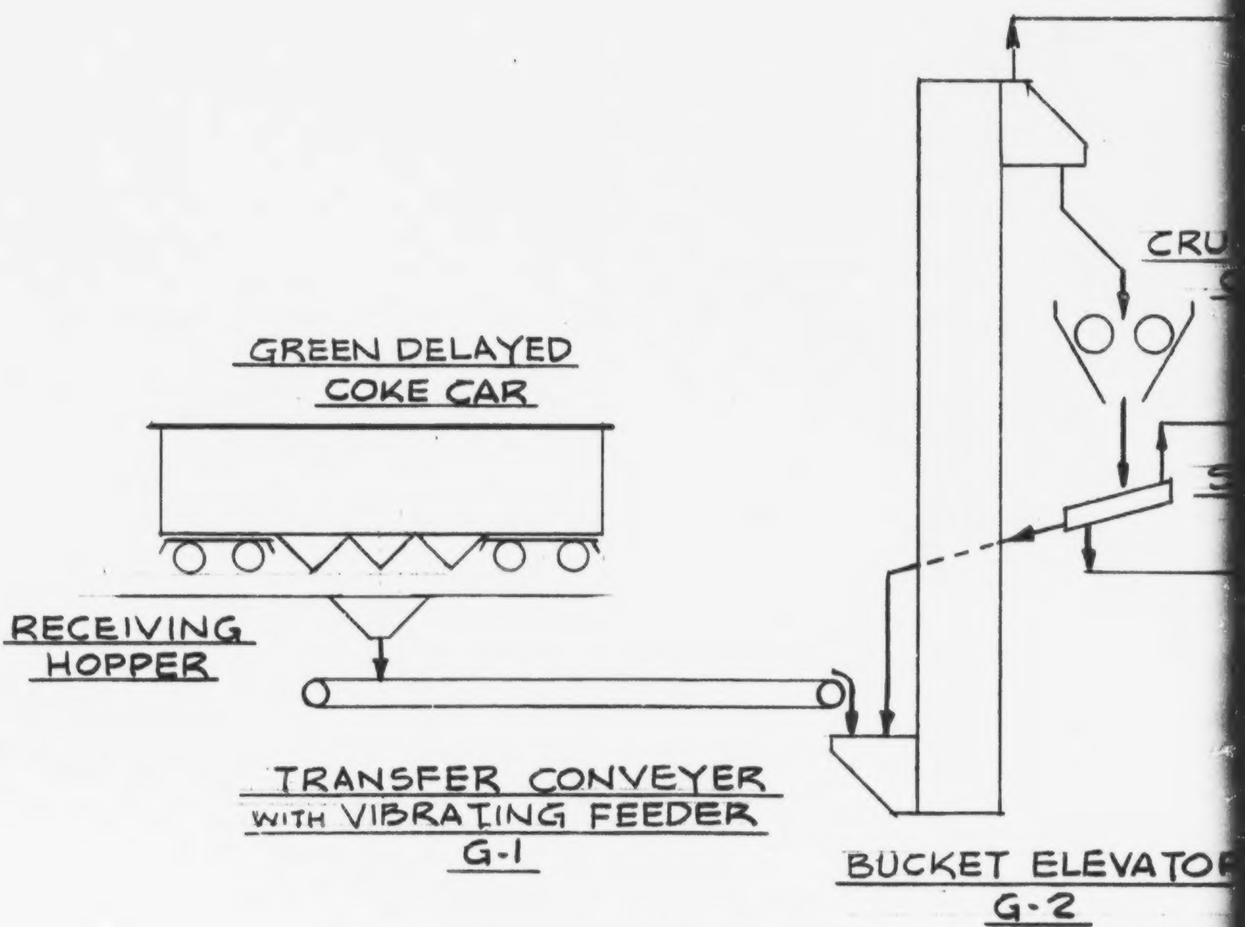
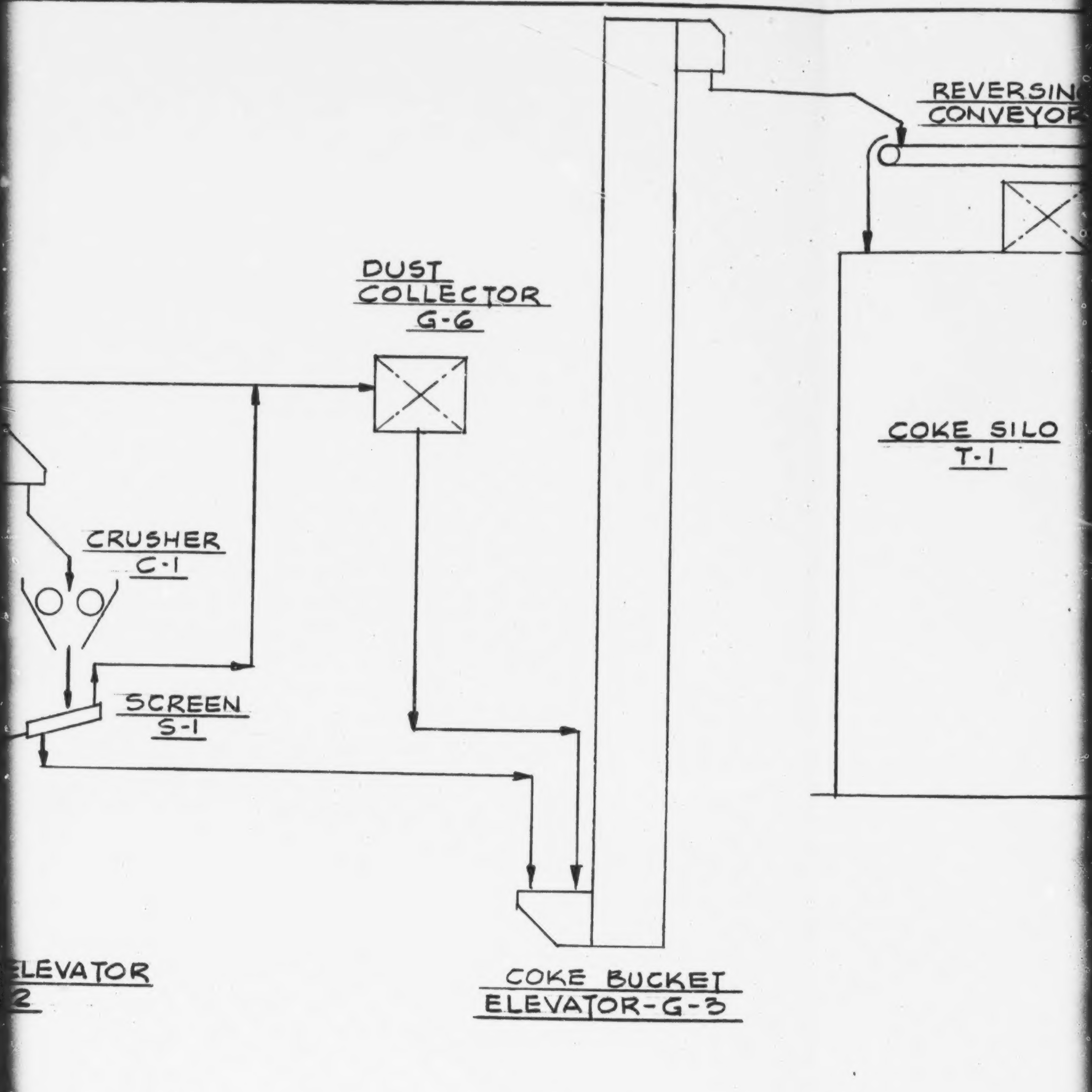
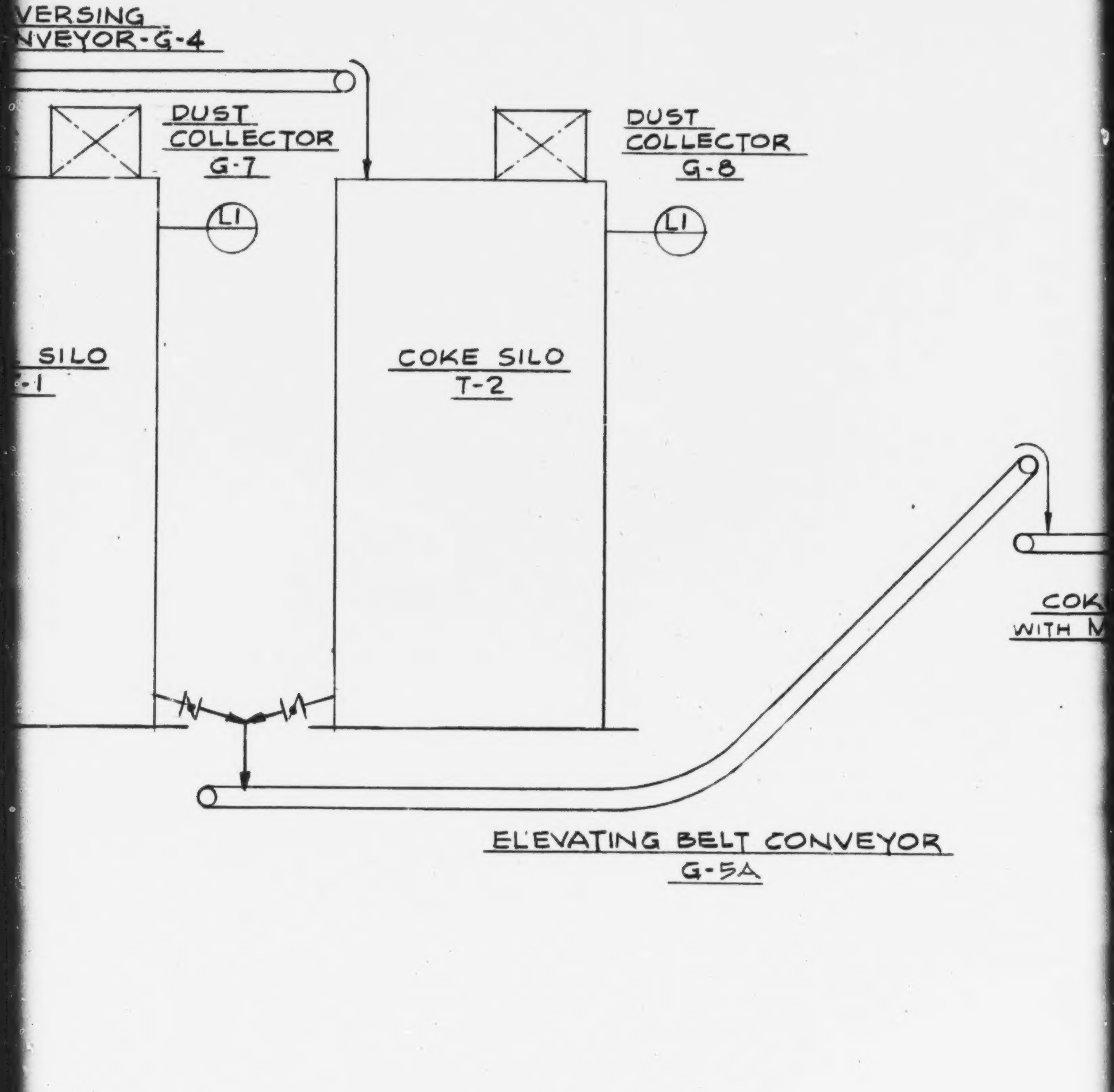

GREEN DELAYED
COKE CAR
RECEIVING
HOPPER
TRANSFER CONVEYER
WITH VIBRATING FEEDER
G-1
BUCKET ELEVATOR
G-2
CRU
S

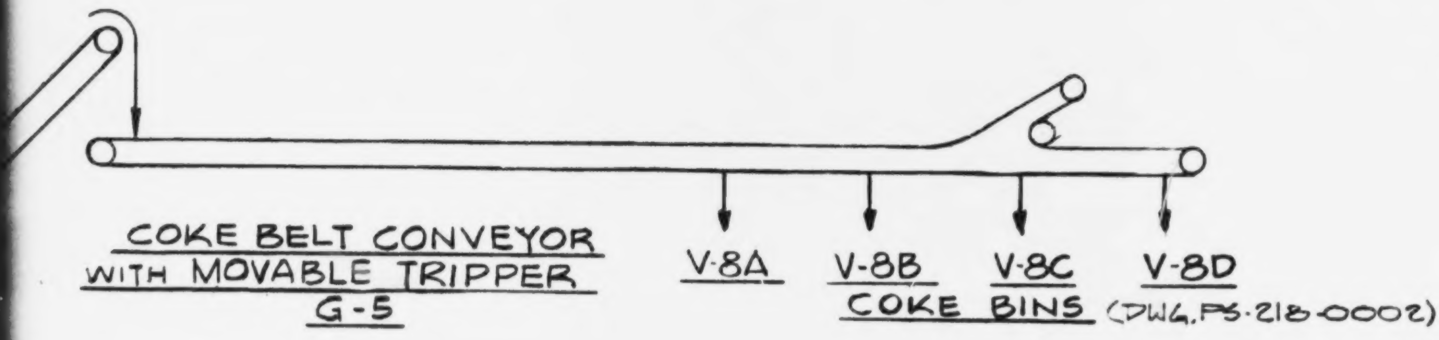
A


REVERSIN
CONVEYOR
DUST COLLECTOR G-6
COKE SILO T-1
CRUSHER C-1
SCREEN S-1
ELEVATOR
2
COKE BUCKET ELEVATOR-G-3

B


VERSING
NVEYOR-G-4
DUST
COLLECTOR
G-7
LI
SILO
-1
DUST
COLLECTOR
G-8
LI
COKE SILO
T-2
COK
WITH M
ELEVATING BELT CONVEYOR
G-5A

C


COKE BELT CONVEYOR
WITH MOVABLE TRIPPER
G-5
V-8A
V-8B
V-8C
V-8D
COKE BINS
(DWG. PS-218-0002)

| DWG Nº | REV |
|---|---|
| PS-218-0003 | 0 |

SINGMASTER & BREYER

NATIONAL AIR POLLUTION
CONTROL ADMINISTRATION

ATOMICS INTERNATIONAL
MOLTEN CARBONATE PROCESS

ENGINEERING FLOW DIAGRAM
COKE HANDLING

| | | | | |
|---|---|---|---|---|
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| CH BY | CLIENT APP | DATE | PS-218-0003 | 0 |
| SCALE | | | | |

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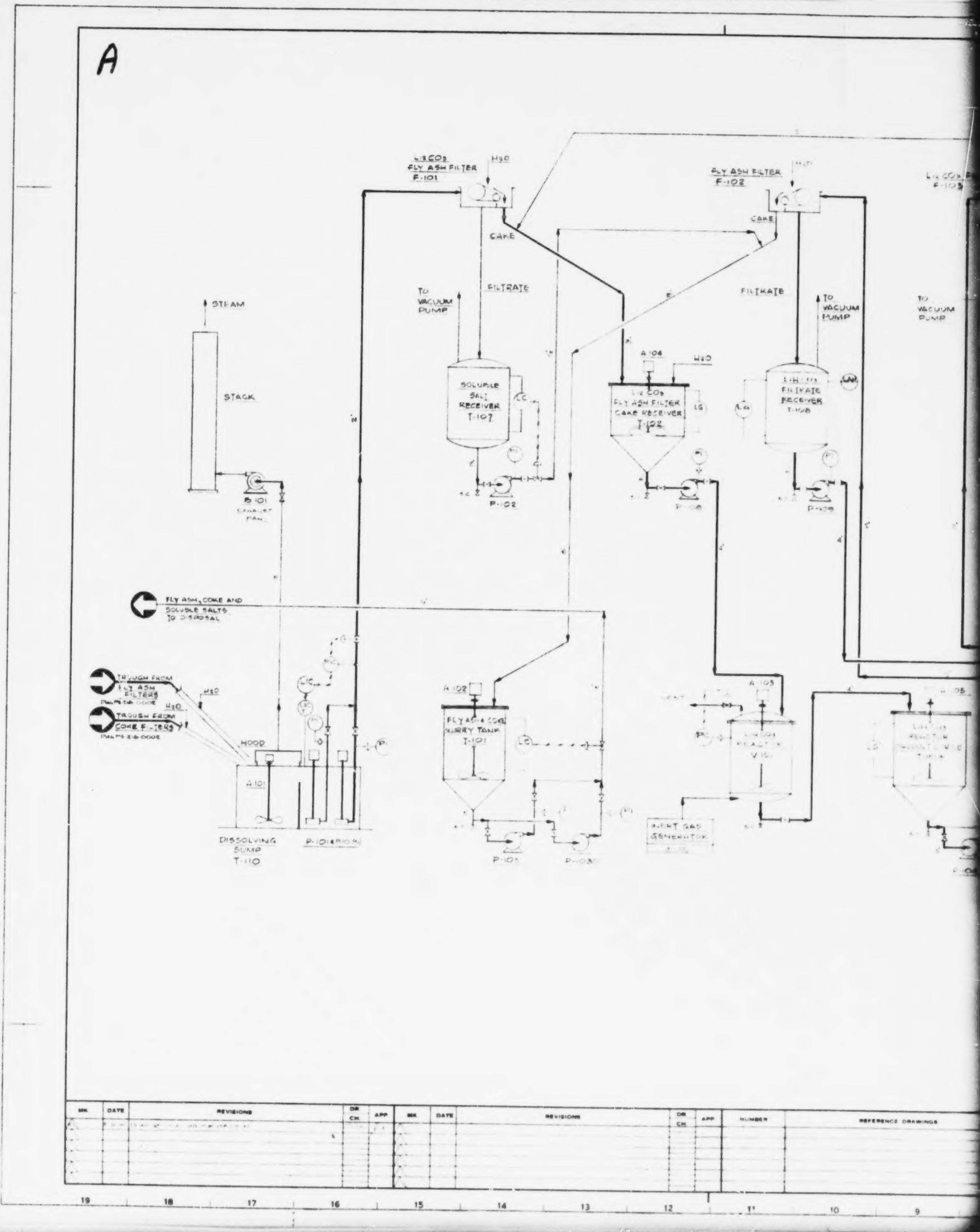
A
$Li_2CO_3$
FLY ASH FILTER
F-101
$H_2O$
CAKE
FILTRATE
TO
VACUUM
PUMP
STEAM
STACK
B-101
EXHAUST
FAN
SOLUBLE
SALT
RECEIVER
T-107
LC
PI
P-102
FLY ASH FILTER
F-102
CAKE
FILTRATE
TO
VACUUM
PUMP
A-104
$H_2O$
$Li_2CO_3$
FLY ASH FILTER
CAKE RECEIVER
T-102
LG
PI
P-108
FILTRATE
RECEIVER
T-108
LG
LAH
PI
P-109
$Li_2CO_3$
F-103
TO
VACUUM
PUMP
FLY ASH, COKE AND
SOLUBLE SALTS
TO DISPOSAL
TROUGH FROM
FLY ASH
FILTERS
TROUGH FROM
COKE FILTERS
$H_2O$
$H_2O$
HOOD
A-101
LIC
PI
PI
DISSOLVING
SUMP
T-110
P-101 & P-101(R)
A-102
FLY ASH & COKE
SLURRY TANK
T-101
LC
PI
P-10?
P-103
VENT
PC
A-103
$Li_2CO_3$
REACTOR
V-101
INERT GAS
GENERATOR
A-105
LG
REACTOR
T-104
MK
DATE
REVISIONS
DR
CH
APP
MK
DATE
REVISIONS
DR
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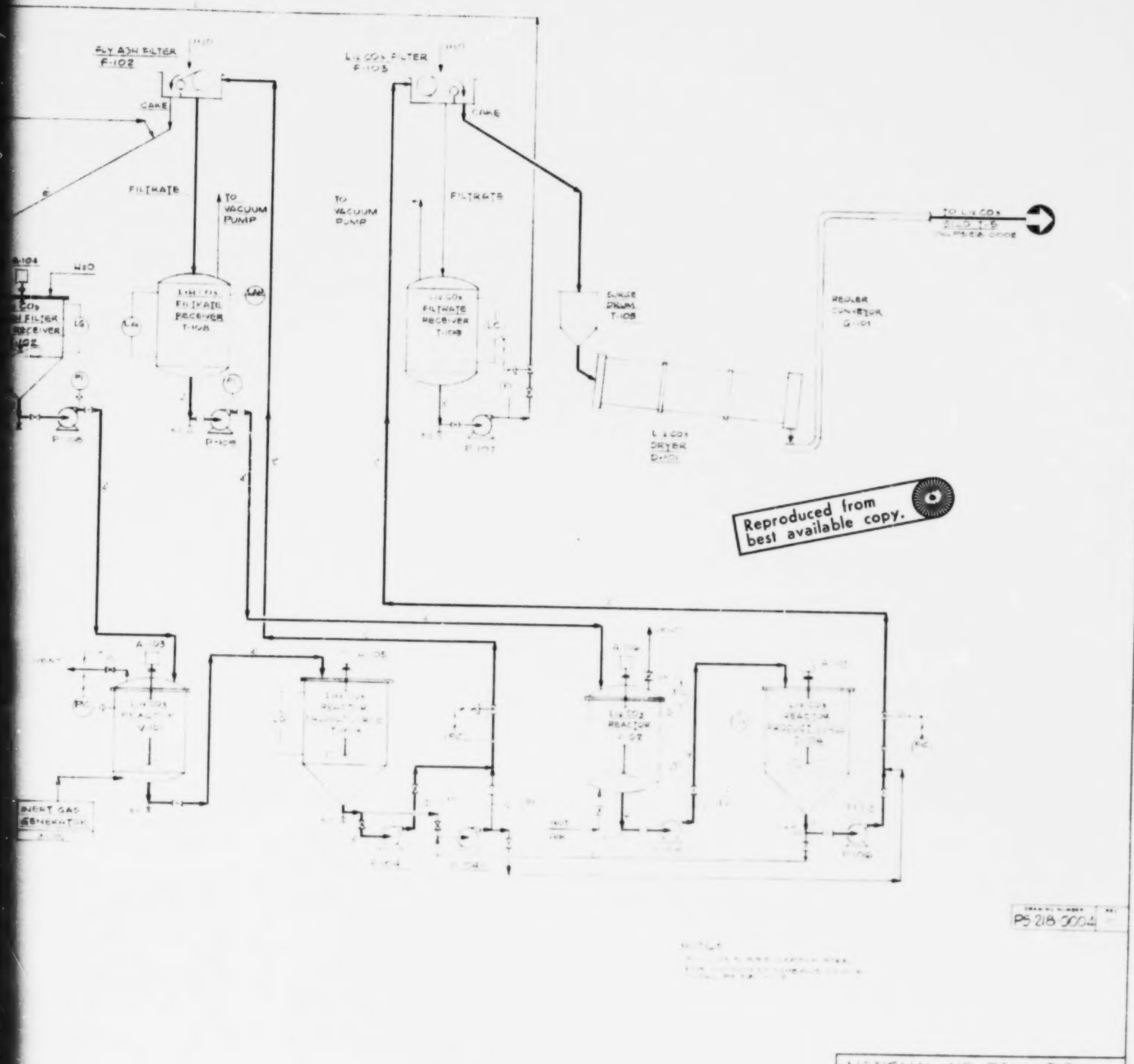
FLY ASH FILTER F-102
$H_2O$
CAKE
FILTRATE
TO VACUUM PUMP
$Li_2CO_3$ FILTER F-103
$H_2O$
CAKE
TO VACUUM PUMP
FILTRATE
A-104
$H_2O$
$Li_2CO_3$ FLY ASH FILTER RECEIVER T-102
LG
$Li_2CO_3$ FILTRATE RECEIVER T-108
LG
LAH
PI
P-106
P-108
$Li_2CO_3$ FILTRATE RECEIVER T-109
LC
PI
P-107
SURGE DRUM T-108
$Li_2CO_3$ DRYER D-101
ROLLER CONVEYOR C-101
TO $Li_2CO_3$ SILO T-5
A-103
VENT
PC
$Li_2CO_3$ REACTOR V-101
A-105
$Li_2CO_3$ REACTOR PRODUCT TANK
PC
VENT
$Li_2CO_3$ REACTOR V-102
$Li_2CO_3$ REACTOR PRODUCT TANK
PC
INERT GAS GENERATOR
INERT GAS
P-104
P-106
NOTES
PS-218-0004

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| | DR | CH | APP | NUMBER | REFERENCE DRAWINGS |
|---|---|---|---|---|---|

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**SINGMASTER & BREYER**
METALLURGICAL AND CHEMICAL PROCESS ENGINEERS
NEW YORK, N.Y. 10017

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

ATOMICS INTERNATIONAL MOLTEN CARBONATE PROCESS

ENGINEERING FLOW DIAGRAM $Li_2CO_3$ RECOVERY

DR. BY
CH. BY
SCALE
S & B APPROVAL
CLIENT APPROVAL
DATE
DWG. NO. PS-218-0004
REV.

12 11 10 9 8 7 6 5 4 3 2

# 4. PLANT CAPITAL AND OPERATING COST ESTIMATES

## a. Base Case (800 MW - 3% S in Coal)

### 1) Capital Cost Estimate

The construction cost estimate for the base case plant is based on the following:

a) The engineering flow diagrams - PS-218-0002, -0003 and -0004.

b) The equipment arrangement drawings - PS-218-0501, -0502 and -0503.

c) No design or engineering development work is included. It is presumed that the technology is known and the engineering costs are those required to implement the design of this known technology.

d) A soil bearing load of 3000 psf.

e) A relatively level and clear site requiring a minimum amount of clearing and grubbing.

f) Steam will be provided from a Claus Plant or the power plant.

g) Sufficient quantities of adequately treated water are available.

h) The estimated cost for construction labor is based on an average wage rate of $6.00 per hour. No premium time is anticipated, nor are travel or time expenses for construction labor.

i) The railroad spur and land acquisition costs are not included.

j) Spare parts, tools and a shop are excluded.

k) A conventional industrial plant electrical system with a feeder from the power plant installed by others. The electrical work starts at a 13.8 KV switching station.

1) Electrical heat tracing of process high temperature lines.

The summary of the Construction Cost Estimate is attached to this section of the report. The Construction Cost Estimate Detail Sheets for the base case plant are appended.

Table 4-1A lists the Total Estimated Capital Requirement for the base case plant and excludes any credit for reduction in height of the power plant stack or reduction in cost of the boiler for reducing corrosion. Furthermore, it does not include the cost of a Claus Plant to recover elemental sulfur.

The capital requirements are based on the following:

1. A penalty for providing a high temperature electrostatic precipitator including the penalty for larger insulated ductwork.

2. The Construction Cost Estimate.

3. The inventory of melt in the process.

4. A contingency of 20%.

5. Interest during construction of 2.3% of the total plant cost.

6. Working capital of 6.5% of the fixed capital cost.

2) Operating Cost Estimate

The operating cost estimate for the base case plant is summarized in Table 4-1B. It is based on the following:

Plant Factor - 70%.

**Raw Material Costs** (Delivered)

| | |
|---|---|
| Delayed Petroleum Coke | - $11/Ton |
| Lithium Carbonate | - 42¢/# |
| Sodium Carbonate | - 2.8¢/# |
| Potassium Carbonate | - 9.6¢/# |

| | |
|---|---|
| **Direct Labor** | - $3.50/hour |
| **Supervision** (Foremen) | - $9,000/year |
| **Maintenance** | - 3% of Fixed Capital Cost |
| **Plant Supplies** | - 15% of Maintenance |

**Utilities**

| | |
|---|---|
| Raw Water | - 10¢/M gal. |
| Boiler Feed Water | - 25¢/M gal. |
| Steam | - assumed available from Claus Plant at no charge. |
| Power | - 6 mills/KWH |
| Fuel (Natural Gas) | - 40¢/MCF |

| | | |
|---|---|---|
| Payroll Burdens | - | 18.5% of direct labor and supervision. |
| Plant Overhead | - | 50% of direct labor, maintenance and plant supplies. |
| Fixed Cost<br>(Capitalization Charge) | - | 14% of the estimated capital requirement to cover depreciation, taxes and insurance. |

The operating cost estimate excludes credits for by-product sulfur, heat recovery and savings in coal costs for using 3% sulfur in coal rather than a lower sulfur coal.

b. Alternate Cases

The construction cost estimates for the alternate cases were developed from the base case plant estimates. The exception is that in the Copper Smelter Reverberatory Furnace Case (Case 10) reheat of an existing 600°F electrostatic precipitator off-gas was considered rather than installing a new electrostatic precipitator. The construction cost summaries for the alternate cases are attached to this section of the report.

The capital requirements and operating cost estimates for the alternate cases were derived from the same unit costs or factors used in the base case plant except for a 90% plant factor used in the Copper Smelter Case. The same exclusions apply to the alternate cases as the base case.

The estimated capital requirements for Cases 2 through 10 are listed in Tables 4-2A through 4-10A. The operating cost estimate for these alternate cases are listed in Tables 4-2B through 4-10B; and for each case are located immediately after its associated estimated capital requirement.

For comparative purposes, the total estimated capital requirements and operating cost estimate for each of the power plant cases are summarized in Table 4-11.

Table 4-1A. Estimated Capital Requirements

Case: 1 (Base)

Plant: 800 MW - 3% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty: | 1,850 |
| Construction Cost Estimate (From Summary Sheet) | 8,338 |
| Total Construction Cost | 10,188 |
| Melt Inventory in Process | 98 |
| Subtotal | 10,286 |
| Contingency | 2,057 |
| Total Plant Cost | 12,343 |
| Interest During Construction (2.3% of Total Plant Cost) | 284 |
| Fixed Capital Cost | 12,627 |
| Working Capital (6.5% of Fixed Capital Cost) | 821 |
| Estimated Capital Requirements | 13,448 |
| $/KW = | 16.81 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-1B. Estimated Annual Operating Costs

Case: 1 (Base)

Plant: 800 MW - 3% Sulfur in Coal

| | (Cost $\$10^3$) |
|---|---|
| A. Direct Costs: | |
| 1) Materials: | |
| Coke | 766 |
| Carbonate | 929 |
| 2) Direct Labor ($3.50/hr) 4/shift | 123 |
| 3) Supervision ($9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 379 |
| 5) Plant Supplies (15% of maintenance) | 57 |
| 6) Utilities | 220 |
| Total Direct Cost | 2,510 |
| B. Indirect Costs: | |
| 1) Payroll Burdens (18.5% of direct labor & supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 280 |
| Total Indirect Cost | 310 |
| C. Fixed Costs: | |
| (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 1,883 |
| Total Annual Operating Cost (1) | 4,703 |
| Mills/KWH | 0.95 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-2A. Estimated Capital Requirements

Case: 2

Plant: 800 MW - 1% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty: | 830 |
| Construction Cost Estimate (From Summary Sheet) | 6,236 |
| Total Construction Cost | 7,066 |
| Melt Inventory in Process | 33 |
| Subtotal | 7,099 |
| Contingency | 1,420 |
| Total Plant Cost | 8,519 |
| Interest During Construction (2.3% of Total Plant Cost) | 196 |
| Fixed Capital Cost | 8,715 |
| Working Capital (6.5% of Fixed Capital Cost) | 566 |
| Estimated Capital Requirements | 9,281 |
| $/KW = | 11.60 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

Table 4-2B. Estimated Annual Operating Costs

Case: 2

Plant: 800 MW - 1% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| A. Direct Cost | |
| 1) Materials | |
| Coke | 255 |
| Carbonate | 721 |
| 2) Direct Labor ($3.50/hr) | 123 |
| 3) Supervision ($9,000/yr) | 36 |
| 4) Maintenance (3% of fixed capital) | 261 |
| 5) Plant Supplies (15% of maintenance) | 39 |
| 6) Utilities | 151 |
| Total Direct Cost | 1,586 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 212 |
| Total Indirect Cost | 242 |
| C. Fixed Cost | |
| (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 1,299 |
| Total Annual Operating Cost (1) | 3,129 |
| Mills/KWH | 0.63 |

(1) Excludes credits for byproduct sulfur and heat recovery.

## Table 4-3A. Estimated Capital Requirements

Case: 3

Plant: 800 MW - 6% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 1,972 |
| Construction Cost Estimate (From Summary Sheet) | 10,028 |
| Total Construction Cost | 12,000 |
| Melt Inventory in Process | 196 |
| Subtotal | 12,196 |
| Contingency | 2,439 |
| Total Plant Cost | 14,635 |
| Interest During Construction (2.3% of Total Plant Cost) | 337 |
| Fixed Capital Cost | 14,972 |
| Working Capital (6.5% of Fixed Capital Cost) | 973 |
| Estimated Capital Requirements | 15,945 |
| $/KW = | 19.93 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-3B. Estimated Annual Operating Costs

Case: 3

Plant: 800 MW - 6% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| **A. Direct Cost** | |
| 1) Materials | |
| Coke | 1,532 |
| Carbonate | 1,241 |
| 2) Direct Labor ($3.50/hr) 4/shift | 123 |
| 3) Supervision ($9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 449 |
| 5) Plant Supplies (15% of maintenance) | 67 |
| 6) Utilities | 324 |
| Total Direct Cost | 3,772 |
| **B. Indirect Cost** | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 320 |
| Total Indirect Cost | 350 |
| **C. Fixed Cost** | |
| (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 2,232 |
| Total Annual Operating Cost(1) | 6,354 |
| Mills/KWH | 1.28 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-4A. Estimated Capital Requirements

Case: 4

Plant: 400 MW - 3% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 1,000 |
| Construction Cost Estimate (From Summary Sheet) | 5,320 |
| Total Construction Cost | 6,320 |
| Melt Inventory in Process | 49 |
| Subtotal | 6,369 |
| Contingency | 1,274 |
| Total Plant Cost | 7,643 |
| Interest During Construction (2.3% of Total Plant Cost) | 176 |
| Fixed Capital Cost | 7,819 |
| Working Capital (6.5% of Fixed Capital Cost) | 508 |
| Estimated Capital Requirements | 8,327 |
| $/KW = | 20.82 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-4B. Estimated Annual Operating Costs

Case: 4

Plant: 400 MW - 3% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| **A. Direct Cost** | |
| 1) Materials | |
| Coke | 383 |
| Carbonate | 465 |
| 2) Direct Labor ($3.50/hr) 4/shift | 123 |
| 3) Supervision ($9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 234 |
| 5) Plant Supplies (15% of maintenance) | 35 |
| 6) Utilities | 110 |
| Total Direct Cost | 1,386 |
| **B. Indirect Cost** | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 196 |
| Total Indirect Cost | 226 |
| **C. Fixed Cost** | |
| (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 1,166 |
| Total Annual Operating Cost (1) | 2,778 |
| Mills/KWH | 1.12 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-5A. Estimated Capital Requirements

Case: 5

Plant: 400 MW - 1% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 420 |
| Construction Cost Estimate (From Summary Sheet) | 4,184 |
| Total Construction Cost | 4,604 |
| Melt Inventory in Process | 16 |
| Subtotal | 4,620 |
| Contingency | 924 |
| Total Plant Cost | 5,544 |
| Interest During Construction (2.3% of Total Plant Cost) | 128 |
| Fixed Capital Cost | 5,672 |
| Working Capital (6.5% of Fixed Capital Cost) | 369 |
| Estimated Capital Requirements | 6,041 |
| $/KW = | 15.10 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

Table 4-5B. Estimated Annual Operating Costs

Case: 5

Plant: 400 MW - 1% Sulfur in Coal

| | Cost ($\$10^3$) |
|---|---|
| A. Direct Cost | |
| 1) Materials | |
| Coke | 127 |
| Carbonate | 361 |
| 2) Direct Labor (\$3.50/hr) 4/shift | 123 |
| 3) Supervision (\$9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 170 |
| 5) Plant Supplies (15% of maintenance) | 26 |
| 6) Utilities | 76 |
| Total Direct Cost | 919 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 160 |
| Total Indirect Cost | 190 |
| C. Fixed Cost (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 846 |
| Total Annual Operating Cost(1) | 1,955 |
| Mills/KWH | 0.79 |

(1) Excludes credits for byproduct sulfur and heat recovery premium.

## Table 4-6A. Estimated Capital Requirements

Case: 6

Plant: 400 MW - 6% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 1,060 |
| Construction Cost Estimate (From Summary Sheet) | 6,383 |
| Total Construction Cost | 7,443 |
| Melt Inventory in Process | 98 |
| Subtotal | 7,541 |
| Contingency | 1,508 |
| Total Plant Cost | 9,049 |
| Interest During Construction (2.3% of Total Plant Cost) | 208 |
| Fixed Capital Cost | 9,257 |
| Working Capital (6.5% of Fixed Capital Cost) | 602 |
| Estimated Capital Requirements | 9,859 |
| $/KW = | 24.65 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-6B. Estimated Annual Operating Costs

Case: 6

Plant: 400 MW - 6% Sulfur in Coal

| | Cost ($\$10^3$) |
|---|---|
| A. Direct Cost | |
| 1) Materials | |
| Coke | 766 |
| Carbonate | 621 |
| 2) Direct Labor (\$3.50/hr) 4/shift | 123 |
| 3) Supervision (\$9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 278 |
| 5) Plant Supplies (15% of maintenance) | 42 |
| 6) Utilities | 162 |
| Total Direct Cost | 2,028 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 222 |
| Total Indirect Cost | 252 |
| C. Fixed Cost (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 1,380 |
| Total Annual Operating Cost(1) | 3,660 |
| Mills/KWH | 1.48 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-7A. Estimated Capital Requirements

Case: 7

Plant: 1000 MW - 3% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 2,130 |
| Construction Cost Estimate (From Summary Sheet) | 10,425 |
| Total Construction Cost | 12,555 |
| Melt Inventory in Process | 123 |
| Subtotal | 12,678 |
| Contingency | 2,536 |
| Total Plant Cost | 15,214 |
| Interest During Construction (2.3% of Total Plant Cost) | 350 |
| Fixed Capital Cost | 15,564 |
| Working Capital (6.5% of Fixed Capital Cost) | 1,012 |
| Estimated Capital Requirements | 16,576 |
| $/KW = | 16.58 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-7B. Estimated Annual Operating Costs

Case: 7

Plant: 1000 MW - 3% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| A. Direct Cost | |
| 1) Materials | |
| Coke | 959 |
| Carbonate | 1,161 |
| 2) Direct Labor ($3.50/hr) 4/shift | 123 |
| 3) Supervision ($9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 467 |
| 5) Plant Supplies (15% of maintenance) | 70 |
| 6) Utilities | 275 |
| Total Direct Cost | 3,091 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 330 |
| Total Indirect Cost | 360 |
| C. Fixed Cost (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 2,321 |
| Total Annual Operating Cost(1) | 5,772 |
| Mills/KWH | 0.93 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-8A. Estimated Capital Requirements

Case: 8

Plant: 1000 MW - 1% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 870 |
| Construction Cost Estimate (From Summary Sheet) | 7,633 |
| Total Construction Cost | 8,503 |
| Melt Inventory in Process | 41 |
| Subtotal | 8,544 |
| Contingency | 1,709 |
| Total Plant Cost | 10,253 |
| Interest During Construction (2.3% of Total Plant Cost) | 236 |
| Fixed Capital Cost | 10,489 |
| Working Capital (6.5% of Fixed Capital Cost) | 682 |
| Estimated Capital Requirements | 11,171 |
| $/KW = | 11.17 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-8B. Estimated Annual Operating Costs

Case: 8

Plant: 1000 MW - 1% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| **A. Direct Cost** | |
| 1) Materials | |
| Coke | 319 |
| Carbonate | 901 |
| 2) Direct Labor ($3.50/hr) 4/shift | 123 |
| 3) Supervision ($9,000/yr) 1/shift | 36 |
| 4) Maintenance (3% of fixed capital) | 315 |
| 5) Plant Supplies (15% of maintenance) | 47 |
| 6) Utilities | 189 |
| Total Direct Cost | 1,930 |
| **B. Indirect Cost** | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 243 |
| Total Indirect Cost | 273 |
| **C. Fixed Cost** (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 1,564 |
| Total Annual Operating Cost(1) | 3,767 |
| Mills/KWH | 0.61 |

(1) Excludes credits for byproduct sulfur and heat recovery.

## Table 4-9A. Estimated Capital Requirements

Case: 9

Plant: 1000 MW - 6% Sulfur in Coal

| | Cost ($10$^3$) |
|---|---|
| Electrostatic Precipitator Penalty | 2,352 |
| Construction Cost Estimate (From Summary Sheet) | 12,648 |
| Total Construction Cost | 15,000 |
| Melt Inventory in Process | 245 |
| Subtotal | 15,245 |
| Contingency | 3,049 |
| Total Plant Cost | 18,294 |
| Interest During Construction (2.3% of Total Plant Cost) | 431 |
| Fixed Capital Cost | 18,725 |
| Working Capital (6.5% of Fixed Capital Cost) | 1,217 |
| Estimated Capital Requirements | 19,942 |
| $/KW = | 19.94 |

The following are excluded:

(1) The total installed cost of the electrostatic precipitator. Includes only the differential cost for using a 99.5% efficient high temperature electrostatic precipitator instead of a 99% efficient low temperature electrostatic precipitator.

(2) The cost of a Claus Plant for recovery of elemental sulfur.

(3) The credits for reducing power plant stack height and reducing corrosion at the low temperature portion of the boiler.

## Table 4-9B. Estimated Annual Operating Costs

Case: 9

Plant: 1000 MW - 6% Sulfur in Coal

| | Cost ($$10^3$) |
|---|---|
| A. Direct Cost | |
| 1) Materials | |
| Coke | 1,915 |
| Carbonate | 1,551 |
| 2) Direct Labor ($3.50/hr) 4/Shift | 123 |
| 3) Supervision ($9,000/yr) 1/Shift | 36 |
| 4) Maintenance (3% of fixed capital) | 562 |
| 5) Plant Supplies (15% of maintenance) | 84 |
| 6) Utilities | 405 |
| Total Direct Cost | 4,676 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 30 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 385 |
| Total Indirect Cost | 415 |
| C. Fixed Cost (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 2,792 |
| Total Annual Operating Cost(1) | 7,883 |
| Mills/KWH | 1.27 |

(1) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

## Table 4-10A. Estimated Capital Requirements

Case: 10

Plant: 200 T/D Copper Smelter Reverberatory Furnace
Equivalent Sulfur in Gases - 50 T/D

| | Cost ($$10^3$) |
|---|---|
| Reheat System | 376 |
| Construction Cost Estimate (From Summary Sheet) | 2,297 |
| Total Construction Cost | 2,673 |
| Melt Inventory in Process | 25 |
| Subtotal | 2,698 |
| Contingency | 540 |
| Total Plant Cost | 3,238 |
| Interest During Construction (2.3% of Total Plant Cost) | 74 |
| Fixed Capital Cost | 3,312 |
| Working Capital (6.5% of Fixed Capital Cost) | 215 |
| Estimated Capital Requirements | 3,527 |

The following is excluded:

(1) The cost of a Claus Plant for recovery of elemental sulfur.

## Table 4-10B. Estimated Annual Operating Costs

Case: 10

Plant: 200 T/D Copper Smelter Reverberatory Furnace
Equivalent Sulfur in Gases - 50 T/D

| | Cost ($\$10^3$) |
|---|---|
| A. Direct Cost: - 90% Plant Factor | |
| 1) Materials | |
| Coke | 246 |
| Carbonate | 118 |
| 2) Direct Labor ($3.50/hr) 2/Shift | 62 |
| 3) Supervision ($9,000/yr) 1/Shift | 36 |
| 4) Maintenance (3% of fixed capital) | 99 |
| 5) Plant Supplies (15% of maintenance) | 15 |
| 6) Utilities | 50 |
| Total Direct Cost | 626 |
| B. Indirect Cost | |
| 1) Payroll Burdens (18.5% of direct labor and supervision) | 18 |
| 2) Plant Overhead (50% of direct labor, maintenance and plant supplies) | 88 |
| Total Indirect Cost | 106 |
| C. Fixed Cost (14% of estimated capital requirement to cover depreciation, taxes and insurances) | 494 |
| Total Annual Operating Cost(1) | 1,226 |
| $/Ton of Copper | 18.66 |

(1) Excludes credits for byproduct sulfur and heat recovery.

Table 4-11. Comparison of Capital & Operating Cost for $SO_x$ Removal from Power Plants

| Power Plant | | | Capital Requirements (1) | | Operating Cost (2) | |
|---|---|---|---|---|---|---|
| Case No. | MW | Sulfur in Coal | $x$10^3$ | $/KW | $x$10^3$/year | Mills/KWH( |
| 1 (Base) | 800 | 3% | 13,448 | 16.81 | 4,703 | 0.95 |
| 2 | 800 | 1 | 9,281 | 11.60 | 3,127 | 0.63 |
| 3 | 800 | 6 | 15,945 | 19.93 | 6,354 | 1.28 |
| 4 | 400 | 3 | 8,327 | 20.82 | 2,778 | 1.12 |
| 5 | 400 | 1 | 6,041 | 15.10 | 1,955 | 0.79 |
| 6 | 400 | 6 | 9,859 | 24.65 | 3,660 | 1.48 |
| 7 | 1,000 | 3 | 16,576 | 16.58 | 5,772 | 0.93 |
| 8 | 1,000 | 1 | 11,171 | 11.17 | 3,767 | 0.61 |
| 9 | 1,000 | 6 | 19,942 | 19.94 | 7,883 | 1.27 |

Notes:

(1) Includes penalty for high temperature electrostatic precipitator. Excludes cost of Claus Plant and credits for reducing power plant stack height and reducing corrosion in boiler.

(2) Excludes credits for byproduct sulfur, heat recovery and lower cost of high sulfur coal.

(3) Mills/produced KWH at 70% Plant Factor.

# CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

**CUSTOMER** NAPCA **DESCRIPTION** SUMMARY
CASE 1 **PROF. NO.**
**LOCATION** 800 MW **CONT. NO.** PS-218
3% S. IN COAL **MADE BY** J.S.J.
**PROJECT** A.I. MOLTEN CARBONATE PROCESS **APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 83000 | - | - | 830 |
| 100 | Concrete & Masonry | 89700 | - | 120300 | 2100 |
| 200 | Structural Steel | 68000 | - | 157000 | 2250 |
| 300 | Building Components | - | 65500 | - | 655 |
| 400 | Machinery & Equipment | 103110 | 1,964000 | 1,514220 | 3,5813 |
| 500 | Piping | 267400 | - | 401100 | 6685 |
| 600 | Electrical | 149500 | 9800 | 284200 | 4435 |
| 700 | Instruments & Controls | 74230 | - | 477320 | 5515 |
| 800 | Insulation, Painting & Scaffolding | 2610 | 191000 | 1090 | 1947 |
| | DIRECT FIELD COSTS | 837550 | 2,230300 | 2,955,230 | 6,023,0 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70% × L.<br>10% × M. | | | |
| | INDIRECT FIELD COSTS | | | | 881820 |
| | TOTAL FIELD COSTS | | | | 6,904,900 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 1,035 600 |
| | TOTAL FIELD & OFFICE COSTS | | | | 7940500 |
| | Fee 5% | | | | 397000 |
| | Equipment Rental<br>Small Tools } Included in Indirect Field Costs. | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax Not Included. | | | | |
| | SUB-TOTAL | | | | 8337500 |
| 900 | Penalties (Precipitator & Ducts) | | | | 1850000 |
| | Escalation Labor | | | | |
| | Material | | | | |
| | Contingency Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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# CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

**CUSTOMER** NAPCA **DESCRIPTION** SUMMARY
CASE 2 **PROP. NO.**
**LOCATION** 800 MW **CONT. NO.** PS-218
1% S. IN COAL **MADE BY** J. S. J.
**PROJECT** A I. MOLTEN CARBONATE PROCESS **APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 63000 | - | - | 63000 |
| 100 | Concrete & Masonry | 67300 | - | 90300 | 157600 |
| 200 | Structural Steel | 54500 | - | 125500 | 180000 |
| 300 | Building Components | | 65500 | - | 65500 |
| 400 | Machinery & Equipment | 66980 | 1,438000 | 975780 | 2480760 |
| 500 | Piping | 213900 | - | 320900 | 534800 |
| 600 | Electrical | 119600 | 7800 | 227400 | 354800 |
| 700 | Instruments & Controls | 66800 | | 429500 | 496300 |
| 800 | Insulation, Painting & Scaffolding | 2470 | 152800 | 930 | 156200 |
| | DIRECT FIELD COSTS | 654550 | 1,664100 | 2,170310 | 4,488960 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70% x L.<br>10% x M. | | | |
| | INDIRECT FIELD COSTS | | | | 675540 |
| | TOTAL FIELD COSTS | | | | 5164500 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 774700 |
| | TOTAL FIELD & OFFICE COSTS | | | | 593920 |
| | Fee 5% | | | | 297000 |
| | Equipment Rental<br>Small Tools } Included In Indirect Field Cost | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax. Not Included | | | | |
| | SUB-TOTAL | | | | 6236200 |
| 900 | Penalties (Precipitator & Ducts) | | | | 83000 |
| | Escalation Labor | | | | |
| | Material | | | | |
| | Contingency Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

**CUSTOMER** NAPCA.

**DESCRIPTION** SUMMARY
CASE 3
800 MW
6% S. IN COAL

**LOCATION**

**PROP. NO.**

**CONT. NO.** PS-218

**MADE BY** J.S.J.

**PROJECT** A.I. Molten Carbonate Process

**APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 99600 | – | – | 99600 |
| 100 | Concrete & Masonry | 107600 | – | 144400 | 252000 |
| 200 | Structural Steel | 74800 | – | 172700 | 247500 |
| 300 | Building Components | – | 65500 | – | 65500 |
| 400 | Machinery & Equipment | 123410 | 2,256000 | 1,947940 | 4,327350 |
| 500 | Piping | 320800 | – | 481200 | 802000 |
| 600 | Electrical | 179400 | 11700 | 341100 | 532200 |
| 700 | Instruments & Controls | 89100 | - | 572800 | 661900 |
| 800 | Insulation, Painting & Scaffolding | 2880 | 248300 | 1230 | 252410 |
| | DIRECT FIELD COSTS | 997590 | 2,581500 | 3,661370 | 7,240460 |
| | Temporary Construction Facilities | 70% x L<br>10% x M | | | |
| | Miscellaneous Services, Supplies & Expense | | | | |
| | Constr. Tools & Equip. (Service & Handling) | | | | |
| | Travel Time & Expense (Field Personnel) | | | | |
| | Field Staff, Subsistence & Expense | | | | |
| | Craft Fringe Benefits | | | | |
| | Vacation, Sick Leave & Holiday | | | | |
| | Payroll Burdens & Insurance | | | | |
| | INDIRECT FIELD COSTS | | | | 1,064440 |
| | TOTAL FIELD COSTS | | | | 8,304900 |
| | Engineering & Drafting | 15% | | | |
| | Purchasing & Accounting | | | | |
| | Office Expense | | | | |
| | Office Payroll Burdens | | | | |
| | Indirect Costs-Office | | | | |
| | (Engineering Development Cost Not Included) | | | | |
| | TOTAL OFFICE COSTS | | | | 1,245,700 |
| | TOTAL FIELD & OFFICE COSTS | | | | 9,550,600 |
| | Fee 5% | | | | 477400 |
| | Equipment Rental } Included in Indirect Field Costs | | | | |
| | Small Tools | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax Not Included. | | | | |
| | SUB-TOTAL | | | | 10,028000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 1,972,000 |
| | Escalation Labor | | | | |
| | Material | | | | |
| | Contingency Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA

DESCRIPTION SUMMARY CASE 4 400 MW. 3% S. IN COAL

LOCATION

PROP. NO.

CONT. NO. PS-218

MADE BY J.S.J.

PROJECT A1. MOLTEN CARBONATE PROCESS

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 58100 | - | - | 58100 |
| 100 | Concrete & Masonry | 63000 | - | 84200 | 147200 |
| 200 | Structural Steel | 51000 | - | 120000 | 171000 |
| 300 | Building Components | - | 65500 | - | 65500 |
| 400 | Machinery & Equipment | 61870 | 1,178400 | 903540 | 2,143810 |
| 500 | Piping | 187200 | - | 280800 | 468000 |
| 600 | Electrical | 104600 | 6900 | 199000 | 310500 |
| 700 | Instruments & Controls | 44600 | - | 286400 | 331000 |
| 800 | Insulation, Painting & Scaffolding | 1570 | 115000 | 700 | 117270 |
| | DIRECT FIELD COSTS | 571940 | 1,365800 | 1,879640 | 3,817380 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70%×L.<br>10%×M. | | | |
| | INDIRECT FIELD COSTS | | | | 588320 |
| | TOTAL FIELD COSTS | | | | 4405700 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 660800 |
| | TOTAL FIELD & OFFICE COSTS | | | | 5066500 |
| | Fee 5% | | | | 253500 |
| | Equipment Rental } Included In Indirect Field Costs<br>Small Tools } Included In Indirect Field Costs | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax: Not Included. | | | | |
| | SUB-TOTAL | | | | 5,320000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 1,000000 |
| | Escalation Labor<br>Material | | | | |
| | Contingency Labor<br>Material | | | | |
| | TOTAL | | | | |

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA
DESCRIPTION SUMMARY
CASE 5
400 M.W.
1% S. IN COAL
LOCATION
PROP. NO.
CONT. NO. PS 218
MADE BY J.S.J.
PROJECT A.I. Molten Carbonate Process
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 44100 | - | - | 44100 |
| 100 | Concrete & Masonry | 47200 | - | 63300 | 110500 |
| 200 | Structural Steel | 40900 | - | 93800 | 134700 |
| 300 | Building Components | - | 65500 | - | 65500 |
| 400 | Machinery & Equipment | 43540 | 934700 | 634260 | 1,612,500 |
| 500 | Piping | 162300 | - | 224700 | 387000 |
| 600 | Electrical | 83700 | 5500 | 159200 | 248400 |
| 700 | Instruments & Controls | 40100 | - | 257700 | 297800 |
| 800 | Insulation, Painting & Scaffolding | 1500 | 91,700 | 600 | 93800 |
| | DIRECT FIELD COSTS | 463340 | 1097400 | 1433560 | 2994300 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70%xL.<br>10%xM. | | | |
| | INDIRECT FIELD COSTS | | | | 470700 |
| | TOTAL FIELD COSTS | | | | 3465000 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 519800 |
| | TOTAL FIELD & OFFICE COSTS | | | | 3984800 |
| | Fee 5% | | | | 199200 |
| | Equipment Rental } Included in Indirect Field Costs<br>Small Tools } | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax Not Included. | | | | |
| | SUB-TOTAL | | | | 4,184000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 420000 |
| | Escalation Labor<br>Material | | | | |
| | Contingency Labor<br>Material | | | | |
| | TOTAL | | | | |

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FORM E-154

## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA
DESCRIPTION SUMMARY
CASE 6
400 M. W.
6% S. IN COAL
LOCATION
PROP. NO.
CONT. NO. PS-218
MADE BY JSJ.
APPROVED
PROJECT A. I. Molten Carbonate Process

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|
| | | LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
| 000 | Excavation & Grading | 69 800 | - | - | 69 800 |
| 100 | Concrete & Masonry | 75 300 | - | 101 100 | 176 400 |
| 200 | Structural Steel | 56 100 | - | 129 500 | 186 600 |
| 300 | Building Components | - | 65 500 | - | 65 500 |
| 400 | Machinery & Equipment | 74 100 | 1 353 600 | 1,168 300 | 2,596 500 |
| 500 | Piping | 224 600 | - | 336 800 | 561 400 |
| 600 | Electrical | 125 600 | 8 200 | 238 800 | 372 600 |
| 700 | Instruments & Controls | 53 500 | - | 343 700 | 397 200 |
| 800 | Insulation, Painting & Scaffolding | 1 800 | 149 000 | 800 | 151 600 |
| | DIRECT FIELD COSTS | 680 800 | 1,576 300 | 2 319 500 | 4,577 600 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70% × L.<br>10% × M. | | | |
| | INDIRECT FIELD COSTS | | | | 708 600 |
| | TOTAL FIELD COSTS | | | | 5,286 200 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 792 800 |
| | TOTAL FIELD & OFFICE COSTS | | | | 6079 000 |
| | Fee 5% | | | | 304 000 |
| | Equipment Rental<br>Small Tools } Included in Indirect Field Costs | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax | | | | |
| | SUB-TOTAL | | | | 6,383 000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 1,060 000 |
| | Escalation Labor | | | | |
| | Material | | | | |
| | Contingency Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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FORM E-154

# CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA
DESCRIPTION SUMMARY
CASE 7
1000 M.W.
3% S. IN COAL
LOCATION
PROJECT A1. MOLTEN CARBONATE PROCESS
PROF. NO.
CONT. NO. PS-218
MADE BY J.S.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED LABOR | SUB.CONTRACTS | MATERIALS | TOTAL |
|---|---|---|---|---|---|
| 000 | Excavation & Grading | 103000 | - | - | 103000 |
| 100 | Concrete & Masonry | 116200 | - | 147900 | 264100 |
| 200 | Structural Steel | 84600 | - | 197500 | 282100 |
| 300 | Building Components | - | 78600 | - | 78600 |
| 400 | Machinery & Equipment | 128900 | 2,455000 | 1,892800 | 4,476700 |
| 500 | Piping | 340200 | - | 510300 | 850500 |
| 600 | Electrical | 177300 | 10700 | 349200 | 537200 |
| 700 | Instruments & Controls | 104400 | - | 585000 | 689400 |
| 800 | Insulation, Painting & Scaffolding | 4000 | 236600 | 2000 | 242600 |
| | DIRECT FIELD COSTS | 1,058600 | 2,780900 | 3,684700 | 7,524200 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70%xL<br>10%xM. | | | |
| | INDIRECT FIELD COSTS | | | | 1,109,500 |
| | TOTAL FIELD COSTS | | | | 8,633700 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 1,295000 |
| | TOTAL FIELD & OFFICE COSTS | | | | 9,928700 |
| | Fee 5% | | | | 496300 |
| | Equipment Rental<br>Small Tools } Included in Indirect Field Costs. | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax Not Included | | | | |
| | SUB-TOTAL | | | | 10,425000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 2,13000 |
| | Escalation Labor<br>Material | | | | |
| | Contingency Labor<br>Material | | | | |
| | TOTAL | | | | |

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# CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

**CUSTOMER** NAPCA **DESCRIPTION** SUMMARY

CASE 8

1000 M. W.

1% S. in Coal

**PROP. NO.**

**LOCATION**

**CONT. NO.** PS-21F

**MADE BY** J.S.J.

**PROJECT** A.I. Molten Carbonate Process

**APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST (CENTS OMITTED) LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
|---|---|---|---|---|---|
| 000 | Excavation & Grading | 71300 | - | - | 71300 |
| 100 | Concrete & Masonry | 80500 | - | 102400 | 182900 |
| 200 | Structural Steel | 58600 | - | 136800 | 195400 |
| 300 | Building Components | - | 78600 | - | 78600 |
| 400 | Machinery & Equipment | 83700 | 1,797500 | 1,519700 | 3,400900 |
| 500 | Piping | 235700 | - | 353500 | 589200 |
| 600 | Electrical | 123300 | 7000 | 241800 | 372100 |
| 700 | Instruments & Controls | 72500 | - | 405000 | 477500 |
| 800 | Insulation, Painting & Scaffolding | 3400 | 162500 | 1600 | 167500 |
|  | DIRECT FIELD COSTS | 729000 | 2,045600 | 2,760800 | 5,535400 |
|  | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70%xL<br>10%xM |  |  |  |
|  | INDIRECT FIELD COSTS |  |  |  | 786400 |
|  | TOTAL FIELD COSTS |  |  |  | 6321800 |
|  | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% |  |  |  |
|  | TOTAL OFFICE COSTS |  |  |  | 948200 |
|  | TOTAL FIELD & OFFICE COSTS |  |  |  | 7270000 |
|  | Fee 5% |  |  |  | 363000 |
|  | Equipment Rental } Included in Indirect Field Cost |  |  |  |  |
|  | Small Tools } Included in Indirect Field Cost |  |  |  |  |
|  | Royalty/Know-How |  |  |  |  |
|  | Sales Tax Not Included. |  |  |  |  |
|  | SUB-TOTAL |  |  |  | 7633000 |
| 900 | Penalties (Precipitator & Ducts) |  |  |  | 870000 |
|  | Escalation Labor |  |  |  |  |
|  | Material |  |  |  |  |
|  | Contingency Labor |  |  |  |  |
|  | Material |  |  |  |  |
|  | TOTAL |  |  |  |  |

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA DESCRIPTION SUMMARY
CASE 9 PROP. NO.
LOCATION 1000 M.W. CONT. NO. PS-218
6% S. IN COAL MADE BY J.S.J.
PROJECT A.I. Molten Carbonate Process APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST CENTS OMITTED LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
|---|---|---|---|---|---|
| 000 | Excavation & Grading | 124400 | – | – | 124400 |
| 100 | Concrete & Masonry | 141600 | – | 177500 | 319100 |
| 200 | Structural Steel | 119300 | – | 221500 | 340800 |
| 300 | Building Components | – | 78600 | – | 78600 |
| 400 | Machinery & Equipment | 154300 | 2820000 | 2434900 | 5,409200 |
| 500 | Piping | 411100 | – | 616600 | 1,027700 |
| 600 | Electrical | 233700 | 13000 | 402400 | 649100 |
| 700 | Instruments & Controls | 166600 | – | 666400 | 833000 |
| 800 | Insulation, Painting & Scaffolding | 3900 | 286300 | 1900 | 292100 |
| | DIRECT FIELD COSTS | 1,354900 | 3197900 | 4521200 | 9,074000 |
| | Temporary Construction Facilities | 70% x L<br>10% x M. | | | |
| | Miscellaneous Services, Supplies & Expense | | | | |
| | Constr. Tools & Equip. (Service & Handling) | | | | |
| | Travel Time & Expense (Field Personnel) | | | | |
| | Field Staff, Subsistence & Expense | | | | |
| | Craft Fringe Benefits | | | | |
| | Vacation, Sick Leave & Holiday | | | | |
| | Payroll Burdens & Insurance | | | | |
| | INDIRECT FIELD COSTS | | | | 1,400500 |
| | TOTAL FIELD COSTS | | | | 10474500 |
| | Engineering & Drafting | 15% | | | |
| | Purchasing & Accounting | | | | |
| | Office Expense | | | | |
| | Office Payroll Burdens | | | | |
| | Indirect Costs-Office | | | | |
| | (Engineering Development Cost Not Included) | | | | |
| | TOTAL OFFICE COSTS | | | | 1,571200 |
| | TOTAL FIELD & OFFICE COSTS | | | | 12,045700 |
| | Fee 5% | | | | 602300 |
| | Equipment Rental } Included in Indirect | | | | |
| | Small Tools } Field Costs | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax Not Included | | | | |
| | SUB-TOTAL | | | | 12,648000 |
| 900 | Penalties (Precipitator & Ducts) | | | | 2,352000 |
| | Escalation Labor | | | | |
| | Material | | | | |
| | Contingency Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

**CUSTOMER** NAPCA **DESCRIPTION** SUMMARY
CASE 10 **PROP. NO.**
**LOCATION** Copper Smelter **CONT. NO.** PS-218
**MADE BY** J.J.J.
**PROJECT** A.I. Molten Carbonate Process **APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | ESTIMATED COST (CENTS OMITTED) LABOR | SUB-CONTRACTS | MATERIALS | TOTAL |
|---|---|---|---|---|---|
| 000 | Excavation & Grading | 32000 | — | — | 32 000 |
| 100 | Concrete & Masonry | 40 800 | — | 54200 | 95 000 |
| 200 | Structural Steel | 33000 | - | 77000 | 110 000 |
| 300 | Building Components | — | 55000 | - | 55 000 |
| 400 | Machinery & Equipment | 34800 | 370000 | 465200 | 870 000 |
| 500 | Piping | 68 100 | — | 102 200 | 170 300 |
| 600 | Electrical | 28 800 | 6500 | 75 100 | 110 400 |
| 700 | Instruments & Controls | 21 100 | — | 119 200 | 140 300 |
| 800 | Insulation, Painting & Scaffolding | 1 000 | 46500 | 500 | 48 000 |
| | DIRECT FIELD COSTS | 259 600 | 478 000 | 893400 | 1, 631000 |
| | Temporary Construction Facilities<br>Miscellaneous Services, Supplies & Expense<br>Constr. Tools & Equip. (Service & Handling)<br>Travel Time & Expense (Field Personnel)<br>Field Staff, Subsistence & Expense<br>Craft Fringe Benefits<br>Vacation, Sick Leave & Holiday<br>Payroll Burdens & Insurance | 70%× L.<br>10%× M. | | | |
| | INDIRECT FIELD COSTS | | | | 271 000 |
| | TOTAL FIELD COSTS | | | | 1,902 000 |
| | Engineering & Drafting<br>Purchasing & Accounting<br>Office Expense<br>Office Payroll Burdens<br>Indirect Costs-Office<br>(Engineering Development Cost Not Included) | 15% | | | |
| | TOTAL OFFICE COSTS | | | | 285300 |
| | TOTAL FIELD & OFFICE COSTS | | | | 2 187300 |
| | Fee 5% | | | | 109 700 |
| | Equipment Rental | | | | |
| | Small Tools | | | | |
| | Royalty/Know-How | | | | |
| | Sales Tax | | | | |
| | SUB-TOTAL | | | | 2,297 000 |
| 900 | Penalties (Preheater, Combust. Chamber & Ducts) | | | | 376 000 |
| | Escalation — Labor | | | | |
| | Material | | | | |
| | Contingency — Labor | | | | |
| | Material | | | | |
| | TOTAL | | | | |

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## 5. DISCUSSION OF PROCESS PROBLEMS

In evaluating the Molten Carbonate Process for removal of $SO_x$ from new and existing power plants and copper smelters it has become evident that the available bench scale data are insufficient to fully define the design and economic aspects of the process.

Certain problem areas were recognized by Atomics International; other apparent problem areas have come to light during this study. Still more may become evident in a pilot plant program.

This section of the report contains a discussion of both technical and economic problems that may be encountered should this process be applied to power plants and copper smelters.

### a. Absorber

Atomics International has proposed the following criteria for the design of the absorber:

1) Maximum superficial gas velocity: 25 ft/sec.

2) Inlet molar ratio to the absorber, $M_2CO_3$ to $SO_x$: 10:1 maximum.

3) Melt recycle rate to the absorber: 3:1 maximum.

4) Mol percent $M_2CO_3$ in the absorber exit melt: 68.0 minimum.

Atomics International has reported detailed feasibility studies on the spray absorption of $SO_x$ compounds in molten carbonates. These tests were made on a laboratory bench scale. Effective $SO_x$ removal was determined at superficial column gas velocities as great as 25 ft/sec. The adjustment of experimental results for absorption by the wetted column wall also showed adequate spray absorption at this range of gas velocity.

The absorption of sulfur oxides in molten carbonates was also demonstrated on the bench scale using a wetted wall tube and a baffle column. The use of absorber designs such as slats, trays or packed towers was not excluded by Atomics International for future consideration.

The proposed absorber design criteria are summarized in Figure 5-1 with the design range shown as a cross-hatched area. These demonstration values do not include a small increase in $M_2CO_3$ quantity in the melt, as needed to maintain specified molar

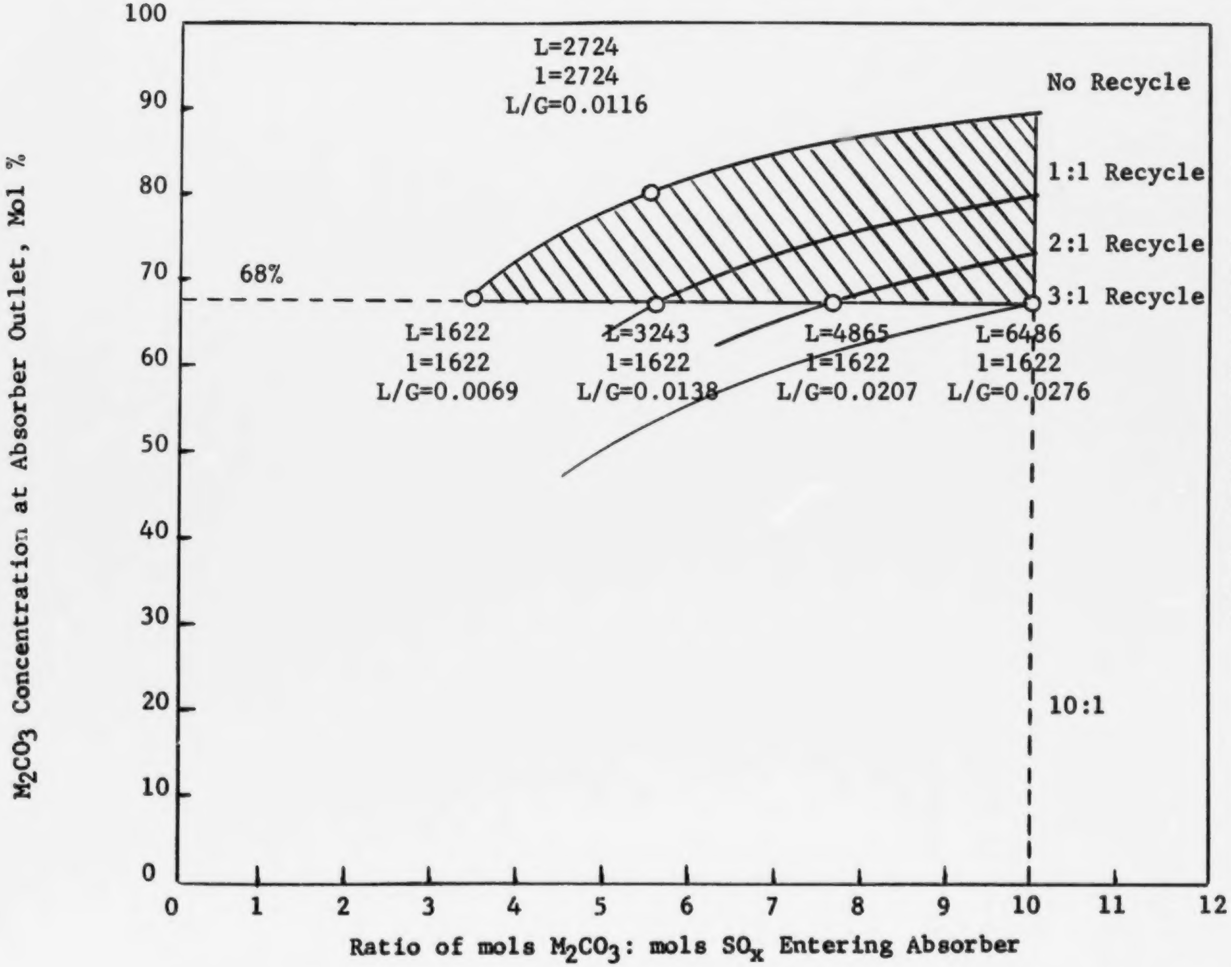


Figure 5-1. Absorber Operating Limits (Based on A-I Design Parameters)

Design range is shown cross hatched.

L is total mols of melt to absorber, per hour.
1 is total mols of melt to reducer, per hour.
G is total mols of gas to absorber, per hour.

Recycle is the number of mols of melt which is returned to the absorber divided by the number of mols of melt advancing to the reducer.

Flow rates pertain to the base case: 800MW, 3% S in coal.

Dissolved KCl not included in melt compositions.

concentrations in the presence of dissolved KCl derived from chlorides contained in the coal.

A 1:1 ratio of absorber melt to fresh melt with 68 mol percent $M_2CO_3$ concentration in the melt at the absorber outlet was selected as a desirable design target. Higher recycle ratios can be achieved by increasing the capacity of the absorber pumps. Such an increase in recycle ratio may be necessary if the absorber design departs from the spray concept proposed by Atomics International. These inlet conditions were used for the material balance appearing in Drawing PS-218-0001, and also in the materials flows presented for the alternate cases. All power plant material balances include dissolved KCl in the melt.

The process flow diagram (Drawing PS-218-0001) shows a $M_2CO_3:SO_x$ ratio of 6:1 with a 1:1 melt recycle ratio. (It should be noted that the corresponding conditions in Figure 5-1 apply to a slightly lower $M_2CO_3:SO_x$ molar ratio of 5.4:1 since dissolved KCl was not included in these demonstration calculations.) This results in an L/G ratio (total mols of melt to total mols of gas) of 0.015, when columns are connected in parallel for both gas and liquid flow. The absorber pumps as designed are capable of a 3:1 melt recirculation ratio. If operated in this manner, the $M_2CO_3:SO_x$ ratio would be about 10:1, giving an L/G ratio of about 0.03.

There are a number of questions which must still be resolved for the final design of the absorber.

1) The performance of a commercial sized absorber with this low L/G ratio is questionable. To improve further the L/G ratio, the absorbers have been designed for series flow on the liquid side (while maintaining parallel gas flow) at the maximum absorber recycle ratio of 3:1. This change further increases the L/G ratio from 0.03 to about 0.12. This series-parallel arrangement, however, changes certain flow characteristics basic to the design of the absorber. Thus, the $M_2CO_3:SO_x$ ratio in the first absorber would be about 40:1. In the other absorbers, the incoming flue gases would come into contact with progressively decreasing concentrations of $M_2CO_3$. The melt leaving the last absorber remains at the specified minimum $M_2CO_3$ concentration of 68 mol percent. The effect of this $M_2CO_3$ concentration gradient requires further examination although the ability to remove $SO_x$ is not expected to be significantly impaired.

2) The scaleup of the absorber design from bench scale data requires confirmation, perhaps more than any other part of the process. Particular attention is needed

to identify the wetted wall effect in bench or pilot scale spray tower absorption. Atomics International has attempted to account for and to correct for the wall effect in their experiments. However, it appears that additional work on a larger unit is necessary to check these initial test results. Wetted wall effects are expected to be minimal in full scale operation.

3) Atomics International found that spray droplet size was critical to absorber efficiency. The critical calculations indicate a droplet in the range of 100 microns should prove effective. Bench scale tests showed that small droplets performed much better than large ones although actual droplet size proved difficult to measure with assurance of accuracy.

The spray nozzles to be used in a commercial unit should be thoroughly evaluated.

4) The demisters will require detailed study. The objective will be to design a demister which will hold melt carryover to an acceptable minimum while conforming with pressure loss considerations, and at the same time not be plugged with melt or fly ash.

Although Atomics International has obtained good $SO_x$ removal efficiencies using high gas velocities, about 25 ft/sec, the possible effects of such high velocities must be determined in a large unit. The prime concern of high gas velocity is that in a spray absorber small droplets of melt will be carried off with the scrubbed gases, in spite of the use of demisters. This loss of melt is undesirable from an economic standpoint and not acceptable from a corrosion standpoint because the scrubbed gases are returned to the boiler where the materials of construction are not likely to be compatible with melt. Furthermore, the melt carryover may be emitted to the atmosphere from the boiler stack causing additional pollution problems.

5) The possible plugging of the spray nozzles producing the fine droplets by fly ash must be checked by additional testing. The melt is recycled to the absorbers upstream of the fly ash filter, in order to reduce the filter load. Consequently, there will be some fly ash in the melt which is recycled to the absorbers which may limit the usefulness of recycle melt if it is needed for flushing the demisters.

6) Another area where further work is desirable is the evaluation of other types of columns, such as a slat tower, tray tower or a packed tower. The work should be performed to evaluate the absorption efficiency at minimum pressure drop and melt carryover. These absorbers do not require as fine a liquid

droplet as the spray tower, and are likely therefore to reduce melt carryover. However, the gas pressure drop is considerably higher for these types than for spray towers and the towers themselves are generally more expensive.

In summary, large scale absorption development is desirable to confirm the bench scale absorption performance reported by Atomics International. Larger scale tests would also define demisting requirements as well as localized effects such as nozzle plugging or solids buildup. The results of such tests would develop a firmer basis for design utilizing the unique absorption properties of molten carbonates.

### b. Reducer

There are a number of problems associated with the reducer which are still to be resolved by further experimentation.

One of the areas which still requires investigation is the matter of materials of construction. From this standpoint this is the most crucial part of the process because the temperature, at 1500° F, is higher than elsewhere in the system.

In Section 6, Paragraph d, there is a discussion of several methods of construction that were investigated. The method selected includes the use of a high alumina brick, such as Alundum, as back-up to Monofrax which is in contact with melt. The Monofrax (which is much costlier than Alundum and has a higher thermal conductivity) is known to be resistant to melt.

The Monofrax, however, is not completely free of voids, and melt which seeps through the Monofrax voids and joints will come into contact with the Alundum. It has been assumed that melt will not detrimentally affect the Alundum but this will have to be tested.

The design of a vessel with three dissimilar materials in contact with each other presents extensive design problems because of differential expansion. It will be necessary to obtain accurate temperature profiles to facilitate the design of such a unit.

The concept of a two-zone reducer is another area which requires additional work to insure operability. The object of the two-zone approach is to separate the oxidation gases - nitrogen (contained in the combustion air), from the reduction gases - essentially $CO_2$ evolved in the reduction of metal sulphates to the metal sulphides. The oxidation gases, after being exchanged against combustion air, are returned to the power plant along with the scrubbed flue gases. The reduction zone gases are fed to the Regenerator.

The mechanical design of the reducer will have to be investigated to determine the proper parameters for making this separation as fine as possible. Factors which will have to be checked include area and configuration of openings between oxidation and reduction sections to obtain proper circulation. It is important to attain a good separation here because any nitrogen from the oxidation section which reports with the reducer gases will go through the Regenerator, into the Claus Plant. Equipment sizing would be affected, and the heat content of the gas not be easily recoverable. Dilution of reduction zone gases, however, may be beneficial to the number of theoretical trays required in the Regenerator (see Section 5, Paragraph d).

A third area where further test work should be performed is in the coke addition. In our estimate, we have allowed for blow tanks for introduction of the coke into the reducer section. However, it might be better (or necessary) to bring the coke in as a slurry with the melt. This could be accomplished by installing an agitated, atmospheric tank ahead of the reducers, where the coke could be added to the melt. The effect that this would have on whether melt input should be to the oxidation or reducer section should be investigated.

While the recovery of relatively pure carbon dioxide from the reducer would be beneficial it is not critical to the success of the process. An alternate source of carbon dioxide would be the absorption of carbon dioxide from a portion of the boiler flue gas in a conventional amine type absorber with subsequent stripping. Neither the capital investment nor the operating cost of such a unit are likely to affect the overall capital investment or total operating cost significantly.

### c. Reducer Off-Gas Cooling

The process scheme as conceived and shown on the Process Flow Diagram utilizes the heat in the Reducer Oxidation Zone off-gases to preheat the incoming combustion air to a temperature of 600° F. As a consequence, the off-gases are cooled from 1500° F to a temperature of approximately 1120° F. (No credit has been taken for the heat content of these gases).

If the off-gases were cooled to 850° F, the combustion air can be heated to 915° F. The Air-Oxidation Zone Exchanger, E-2, has been conservatively designed for this latter case. The coke consumption for raising the combustion air to the 1500° F reducer temperature has been based on the 600° F preheat.

Consideration must be given to the possibility that chlorides dissolved in the reducer melt may vaporize and be carried with the off-gas to condense on the tubes of the exchanger thus seriously reducing the heat transfer coefficient and introducing a serious danger of corrosion. This possibility must be examined during the pilot plant program as to problems in heat transfer as well as the release of chlorides to the flue gas stream returning to the boiler. If it occurs, shot cleaning of the exchanger tubes can be incorporated in the design of the exchanger to minimize the effect of the chloride solids condensing on the tubes. The shot cleaning equipment has not been included in the capital cost estimate.

Carryover of hot melt with the off-gas must also be considered since this too may cause corrosion of the exchanger tubes at temperatures above 1000 °F. At lower surface temperatures, the entrained melt may condense on the tubes to reduce the heat transfer coefficient.

An alternate to preheating combustion air with oxidation zone gases is to use a portion of the waste heat available in the reduced melt or in the Regenerator melt streams. The capital cost for the exchanger to accomplish the air preheat by this method has not been estimated but could approximate the cost of the Air-Oxidation Zone Exchangers. A danger exists in the use of this type of exchanger; the melt is cooled by relatively cold air which may cause freezing. In the air-cooled exchangers presently contemplated for cooling the reduced melt and regenerator streams there is also a danger of freezing melt but these units are equipped with external air bypasses to recirculate hot air to temper the inlet air which will minimize the freezing. They are also equipped with steam coils to heat the air during start-up should this be required. It is probable that a similar system could be designed for a combustion air preheater using hot melt as the source of heat.

There are two advantages that are apparent in eliminating the Air-Oxidation Zone Exchanger.

1) The heat available in the return of 1500 °F off-gas to the boiler above an 850 °F datum is 18 million BTU/HR for the base case plant. This is equivalent to an annual saving assuming the boiler equipment can take advantage of this additional heat, of $33,000 at a value of 30¢ per million BTU.

2) Any problems associated with chloride or melt condensation on exchanger tubes will be eliminated from the process. The gases can be mixed with the absorber off-gas at 850 °F where the small amount of chlorides will condense on contact with the

colder gas and be carried as fine particulate matter to the boiler.

The penalty for not preheating the combustion air is additional coke consumed in the reducer. Waste heat valued at 30¢/million BTU's is being used to replace coke valued at approximately 48¢/million BTU's which would otherwise be required.

The off-gas from the reduction zone of the reducer is cooled to the Regenerator temperature by the addition of water and/or low pressure steam in the amount required for the regeneration reaction.

### d. Regeneration

Atomics International, in their previously reported work, used the McCabe-Thiele approach to determine the number of theoretical trays required for the regenerator. It is believed that this approach is valid from the preliminary information contained in the reports.

The effect of changes in gas composition and flow on the number of theoretical trays required to accomplish the desired regeneration of $M_2S$ contained in the feed melt has been examined.

These studies were based on regenerator tower temperatures ranging between 850-950°F using intermediate coolers and partial recycle of cooled melt to upper trays. Atomics International studies were based on an isothermal regenerator with cooling provided at each tray to maintain the temperature at 850°F.

### Carbon Dioxide Required

The equilibrium curve for $X_{M_2S}$ versus $Y_{H_2S}$ is based on the following Atomics International equilibrium equations:

$$K_{equil} = \frac{1.9 \times 10^{-6} (e^{\frac{28,000}{RT}})}{1 + 1.24 \times 10^{-3} \, P_{CO_2} \, (e^{\frac{15,400}{RT}})} \qquad (1)$$

$$K_{equil} = \frac{X_{M_2CO_3} \; P_{H_2S}}{X_{M_2S} \; P_{CO_2} \; P_{H_2O}} \qquad (2)$$

Substituting

$$K_1 = 1.9 \times 10^{-6} \left(e \frac{28,000}{RT}\right) \text{ and}$$

$$K_2 = 1.24 \times 10^{-3} \left(e \frac{15,400}{RT}\right) \text{ in equation (1) results in}$$

$$K_{equil} = \frac{K_1}{1+K_2P_{CO_2}} \tag{3}$$

Equating equations (2) and (3) at one atmosphere pressure where the partial pressure of the gases are equal to their respective mol fractions results in the following $X_{M_2S}$ equilibrium equation:

$$X_{M2S} = \frac{(X_{M2CO3})\ (Y_{H2S})\ (1+K_2\ Y_{CO2})}{K_1\ (Y_{CO2})\ (Y_{H2O})} \tag{4}$$

at 850 °F, $K_2 = 52.9$

at 950 °F, $K_2 = 24.7$

For a constant $X_{M2CO3}$, $Y_{H2S}$, and $Y_{H2O}$ the equilibrium equation reduces to

$$X_{M2S} = \frac{K_3\ (1+K_2\ Y_{CO_2})}{Y_{CO_2}} \tag{5}$$

When the $CO_2$ concentration in the exit gas is above about 0.04 mol fraction, $K_2Y_{CO_2}$ is the dominant factor in $(1+K_2Y_{CO_2})$ of equation (5) and maintaining a $CO_2$ concentration of two to three times this value will make the equilibrium curve substantially independent of $CO_2$.

Equation (1) was developed empirically by Atomics International on the theory that $M_2S$ and $CO_2$ act to form intermediates such as $M_2CO_2S$. All the tests were carried out with excess amounts of $M_2S$. At the bottom of an actual tower, the concentration of $M_2S$ will be quite small. Therefore, in the lower section of the tower, the independence of the equilibrium curve on $Y_{CO_2}$ may not be valid. If so, this would cause the equilibrium curve to shift unfavorably requiring more theoretical trays. It may be necessary to add only $H_2O$ with less than the required amount of $CO_2$ to the bottom of the tower and the remainder of the $CO_2$ to intermediate points.

### Water Required

Inspection of equation (4) shows that for constant $X_{M_2CO_3}$, $Y_{H_2S}$ and $Y_{CO_2}$, the value of $X_{M_2S}$ is inversely proportional to $Y_{H_2O}$. This means that the equilibrium curve will shift favorably to decrease the number of theoretical trays as $Y_{H_2O}$ increases.

### Number of Theoretical Trays

To substantiate our conclusions regarding the gas concentration effect on the equilibrium curve, calculations were performed to determine the number of theoretical trays at various gas flows and concentrations.

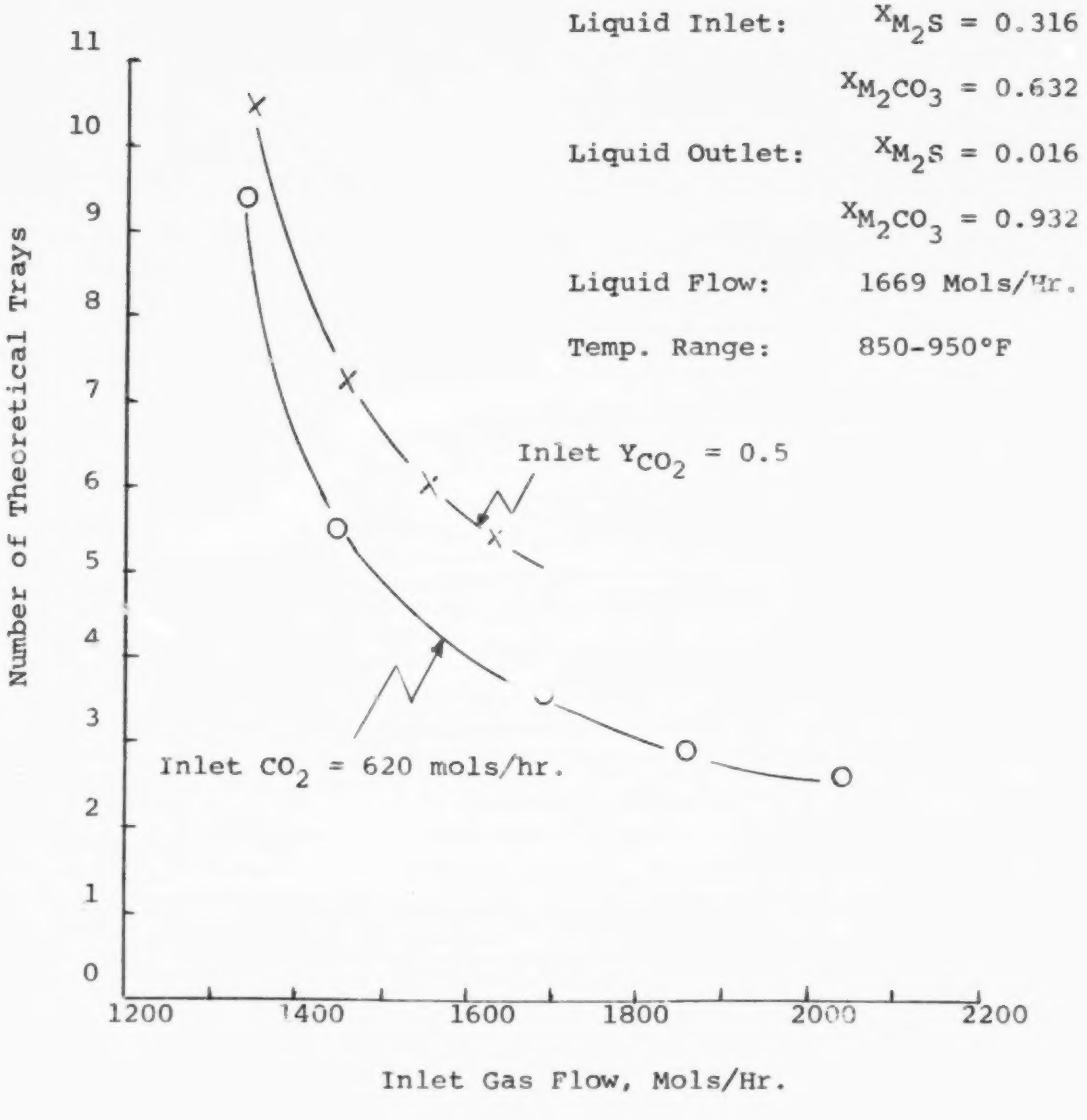
Figure 5-2 shows the number of theoretical trays required for 95% regeneration of $M_2S$ as a function of gas flow for equimolar concentrations of $CO_2$ and $H_2O$. It also shows the effect on the number of theoretical trays for various gas flows with a constant flow of $CO_2$ entering of 620 mols per hour for the base case with the difference constituting $H_2O$. The constant flow of 620 mols per hour was arbitrarily selected to maintain the $CO_2$ mol fraction in the exit gas at approximately 0.08. This is approximately 25 percent above the stoichiometric quantity required as compared to an 85 percent excess indicated by Atomics International.

For the base case, at $Y_{CO_2} = 0.5$ and a $CO_2$ flow of 620 mols per hour, an infinite number of theoretical trays is required even with an isothermal tray.

Stoichiometric quantities of $CO_2$ and $H_2O$ only cannot attain the desired regeneration because it produces a $Y_{H_2S}$ at the regenerator outlet of 1.0 which is above that in equilibrium with the inlet feed.

A diluent gas such as $N_2$ would allow essentially stoichiometric quantities of $CO_2$ and $H_2O$ to be used. The diluent would lower the $Y_{H_2S}$ in the exit gas to a point where it would be in equilibrium with the $X_{M_2S}$ in the feed. However, a greater number of trays would be required as the quantity of $H_2O$ and $CO_2$ approaches the stoichiometric level. Water vapor could also serve as a satisfactory diluent but amounts sufficient to have a significant effect also have a detrimental effect on the performance of the Claus plant.

Figure 5-2. Regenerator Theoretical Trays Versus Inlet Flow



### Tray Efficiency

The actual number of trays depends on tray efficiency for this type of contactor.

Tray efficiencies of distillation systems range between 45 and 90 percent with the lower efficiencies generally indicated for viscous materials greater than 5 cp. It is expected that the tray efficiency in the regenerator would be below 45 percent because

1) of the high viscosity and

2) the reaction rate must be added to a mass transfer rate. Distillation is a mass transfer operation only.

The actual number of trays selected for this study is 15. The theoretical number of trays required is approximately 4 based on equimolar quantities of $CO_2$ and $H_2O$ at an excess of 85% with little or no inert diluents present in the gas. The equivalent tray efficiency is 27 percent. It is expected the design of the two-zone reducer will minimize the inert diluent gases ($N_2$) that can affect the theoretical number of trays.

### Tray Type

Sieve trays were suggested by Atomics International to permit draining of the tower to the pump tanks. However, bubble cap trays or valve trays can be designed for drainage. Sieve trays have a narrow range of liquid to vapor ratio for satisfactory operation which in this case is constantly changing throughout the tower. Bubble cap or valve trays have a greater range of operation. Sieve trays must be relatively level whereas minor variations can be tolerated with bubble cap or valve trays. On this basis, bubble cap trays have been selected for the capital cost estimate.

### Temperature Control

The regeneration reaction is exothermic and must be controlled to hold the temperature above the melting point (750-800 °F) and below 1000 °F to limit corrosion of type 347SS. The range of tower operation has been restricted to between 850 °F and 950 °F. To achieve this control, it is planned to recycle cooled melt from a lower tray in the tower to an upper tray. The design that has been used in this estimate is for one intermediate cooler with partial recycle by temperature control to the top section of the tower and one bottom cooler with partial recycle again under temperature control to the lower section of the tower. This reduces the overall tower efficiency because of the increased liquid to gas ratio and results in a slight increase in the number of trays. A rise in tray temperature is corrected by the addition of cooler melt containing less $M_2S$. This reduces the rate of reaction due to lower temperature and lower concentration of reactants.

More external coolers can be provided to reduce the recycle but each additional cooling unit requires a pump tank, pumps, cooler and controls which will cost substantially more than the cost of additional trays and tower height.

An isothermal tower with cooling coils on each tray can be employed but was not considered for regenerator cooling because of the following disadvantages:

1) A heat transfer medium is required for the coils.

2) The available operating area may be reduced resulting in a larger diameter tower.

3) Higher liquid level will be required on each tray to submerge the coils increasing the pressure drop and back pressure on the reducer operation.

4) Increased costs for installing the tray.

## Tower Design Parameters

The design parameters furnished by Atomics International for sizing the tower are:

| | |
|---|---|
| Superficial Gas Velocity | 4 FPS |
| Holdup Time | 15 minutes |

Based on the net flow of melt feed to the tower, a 19 foot diameter column results in one inch of liquid level per tray to obtain the 15 minute holdup time. If the recycle melt used to cool the trays (1:1 recycle ratio) is assumed to be completely regenerated, the level on each tray will have to be increased to approximately two inches to maintain the holdup time. The actual residence time in the regenerator will probably exceed the 15 minutes. The effect of the pump tanks and external coolers on holdup time has not been considered.

On the basis of a superficial inlet gas velocity of 4 FPS and an 85 percent excess of $CO_2$ and $H_2O$ with no nitrogen or other inert diluents, the tower diameter is less than 14 feet. An 18 foot diameter tower has been arbitrarily selected for the determination of capital cost. Reducing the diameter to 15 feet would lower the capital cost approximately $40,000.

Pilot plant work is required to:

1) Confirm the effect of varying the quantities and concentration of $CO_2$ and $H_2O$ on tower performance and regeneration.

2) Determine the number of trays required to accomplish the regeneration at the expected liquid and gas flows and concentrations.

3) Establish the design parameters such as retention time and superficial gas velocities.

Additional test work should be performed to determine the effect of pressure on regeneration. Increased pressure has the potential for reducing the diameter of the regenerator.

### e. Fly Ash and Coke Filtration

In the Molten Carbonate Process traces of fly ash, as well as sulfur dioxide, are removed from the flue gases. The fly ash must be continuously or periodically removed from the molten salt stream otherwise it would accumulate and make the system inoperable. The fly ash filtration is performed downstream of the absorbers. The coke filtration, to remove the unreacted coke added in the reducers, is performed downstream of the reducers.

Atomics International has done experimental work on fly ash filtration using a Croll-Reynolds wire wound filter. This type of unit is not suitable for a commercial size installation because it is not capable of a "dry cake" discharge. (Dry cake refers to the solids plus associated wetting liquid). Discussions were held with Croll-Reynolds, and they indicated that their unit could not easily be converted to a dry cake discharge type.

In a non-dry cake discharge type of filter, the entire contents of the filter are discharged at the end of each cycle. The filter area required for the fly ash filtration based on data obtained by Atomics International using a Croll-Reynolds test unit is 1000 square feet at a cycle time of 45 minutes. A 1000 square foot Croll-Reynolds filter has a volume of about 2000 gallons. Therefore, 30,000 pounds of melt would be discharged every 45 minutes if such a unit were employed. Such a loss could not, of course, be tolerated. An elaborate recovery system would be required.

Even "dry cake" discharges carry measurable quantities of melt. Atomics International has found that the fly ash cake contains 65% melt, and it has been assumed that the cake from a suitable plant scale filter would contain 50% melt. The implications of these losses are discussed in Section 5, Paragraph f.

Hence, the primary problem associated with the filtration steps is to find a dry cake discharge unit which performs in a satisfactory manner.

Based on discussions with several filter manufacturers the "Auto-Jet" pressure leaf filters, as manufactured by U.S. Filter Corporation, were selected for the capital estimate. Suitability of this type of filter will have to be verified by test. In this type of unit, the liquid contained in the filter is drained and displaced by gas prior to discharging the cake. Hot flue gas or alternatively heated air will have to be used for displacing the melt. The filter leaves are attached to a shaft which rotates against a fixed wire or blade at each leaf during cake discharge.

Atomics International has found the maximum fly ash cake thickness reached within tests is approximately 1/8" at reasonable pressure drops of about 50 psi. This makes it difficult to design a suitable cake-scraping device, since it is desirable not to have such scrapers come too close to the filter media.

Increasing the cake thickness is an area which will have to be investigated in order to apply the U.S. Filter type machine. Coke can possibly be used as a filter aid, introduced as precoat and/or add-mix, to assist in producing a thicker cake and reducing the melt content of the dry cake.

Because of the difficulties involved in mechanically discharging a thin cake, another method was investigated. This entailed the introduction of water directly into the filter at the end of the cycle, to dissolve and sluice out the cake. It is debatable whether this method deserves further study because of many inherent problems.

1. Long periods of time would be required for cool-down and heat-up of equipment prior to reintroduction of melt. Capital costs would be greatly increased because of this necessity for "idle" time.

2. Frequent thermal cycling leads to problems in design and construction of the units.

3. The water initially used for direct cooling flashes

to steam, which is lost, as is the heat content.

4. Possible introduction of water into the melt circuit may not be desirable.

5. Large vents would be required to handle the steam generated (An explosion hazard exists).

It is recommended that this scheme be discarded, and effort concentrated on thickening the cake. In addition to easing the design of the U.S. Filter type of unit, a thicker cake might change the picture in relation to the Croll-Reynolds unit, for now a tank full of liquid would be discharged, say, every 8 hours instead of every 45 minutes.

The calculation of filter area was based on the following empirical relationships developed by A.I.: (Based on a Croll-Reynolds test unit with 25 micron spacing).

$$\frac{\Delta P}{\phi} = 16.3 + 2530\Sigma \qquad \text{For } \Sigma \text{ greater than 0, less than 0.067}$$

$$\frac{\Delta P}{\phi} = 88 + 610\Sigma \qquad \text{For } \Sigma \text{ greater than 0.067, less than 1.25}$$

Where:

$\Delta P$ is pressure drop across filter, psi

$\Sigma$ is ash loading, Lb Ash/ft$^2$ of filter area

$\phi$ is flow rate per unit of filtration area, GPM/ft$^2$

These relationships were developed for the fly ash filter. No correlations were developed for the coke filter. It has been assumed that these equations will hold for the coke filter also. On this basis, the coke filter was calculated to require about the same area, 1000 sq.ft., and have about the same cycle time, 45 minutes, as the fly ash filter. A total of four filters have been allowed - 2 for fly ash filtration and 2 for coke filtration. In final design, three interchangable units may be possible, two operating with one standby and automated for proper time cycling.

The material of construction for all the filters was type 347 stainless steel.

The possibility of using centrifugal separators was discussed with vendors, but discounted because of difficulties associated with the design of high speed rotational equipment at high temperatures and the use of centrifuges is not indicated because of the relatively small difference in melt and filter cake specific gravities.

Several manufacturers declined to propose the use of Rotary Drum Filters because of the service conditions.

### f. Carbonate Makeup

In the Molten Carbonate Process, melt is lost in the cakes discarded from the fly ash and coke filtration steps. In addition, melt can be lost from the process in the absorber offgas. It has been assumed that this loss is negligible and therefore it was not considered in the determination of operating costs. The actual absorber loss can be substantial and must be determined in future test work.

The losses of melt associated with the fly ash and coke filter cakes have been calculated on the following basis:

1. An electrostatic precipitator efficiency of 99.5 percent.

2. Potassium chloride (KCl) solubility in melt is limited to three weight percent and the solids are removed at the fly ash filter.

3. Fly ash and KCl filter cake contains 65 percent melt.

4. The coke filter cake contains 50 percent melt. It also retains the heavy metals contained in the original coke charged to the reducer which must be removed from the process. The coke usage in the reducer and the subsequent unreacted amount to be filtered from the reduced melt is based on carbon oxidation rather than sulfide ($M_2S$) oxidation to provide the reducer sensible heat and heat of reduction. This assumption results in a lesser amount of coke to be filtered than would be anticipated if the heat were provided by M2S oxidation. The $M_2S$ oxidation route could increase the unreacted coke to be filtered by approximately 50 percent.

5. Both fly ash and coke filters provide a dry cake discharge.

6. Lithium carbonate can be recovered to the extent of 88 percent in the aqueous recovery process as conceived. The justification for this process is demonstrated in Section 6, Paragraph f.

7. Potassium and sodium salts are not recovered in the aqueous lithium carbonate recovery process.

The required makeup of sodium, potassium, and lithium carbonates associated with the various "inert" constituents of the filter cakes are indicated in Table 5-1. In addition, the potassium carbonate required for the reaction with chlorides in the flue gas to produce the KCl is also listed in this table.

Inspection of Table 5-1 shows the impact of melt losses on the plant operating costs even with the inclusion of an aqueous process to recover 88 percent of the lithium salts.

In the analysis of melt losses it has been assumed that all of the chlorides in the flue gas react with potassium carbonate ($K_2CO_3$) to form potassium chloride which must be rejected from the process to minimize its buildup. The amount of $K_2CO_3$ required for this reaction is fixed by the chloride content of the coal (0.04%) and results in an annual cost of $220,000 (0.045 mils/KWH). Very little can be done to reduce this cost if the reaction takes place as assumed, except to use coal with a lower chloride content.

The melt losses associated with fly ash filtration depend solely on the "wetness" of the cake discharged from the filter. Laboratory data on the filtration of fly ash in melt using a wedge-wire wound filter element of 25 micron spacing indicated that the cake contained 65 weight percent melt which is understandably high due to the nature of the cake.

The physical form of the fly ash will have a marked affect on melt content of the cake. If the fly ash is in the form of hollow particles, then more melt may be retained by the cake than would be expected with solid particles. Furthermore, no test work has been performed on the filtration characteristics of fly ash that passes through the electrostatic precipitator. This too, may affect the data used in the evaluation.

As stated above, the KCl produced by reaction of chlorides with $K_2CO_3$ must be removed from the process. A conservative approach has been used in this analysis by assuming that the KCl is removed at the fly ash filter and retains the same amount of melt as the fly ash. The melt content of a combined fly ash and KCl filter cake must be determined in future test work. In addition, if a commercial filter provides a dryer cake than is available from a test unit, substantial savings can be realized. Furthermore, an admix (body feed) of coke to the fly ash filter could possibly reduce the cake "wetness". Another possibility to reduce the melt losses associated with fly ash filtration would be to eliminate the step completely and filter the fly ash with the unreacted coke from the

Table 5-1. Carbonate Makeup Requirements - Assuming 88% $Li_2CO_3$ Recovery

Basis: Filter Cake Constituent:
Fly Ash - 225#/Hr ) - Removed at the Fly Ash Filter
KCl - 403#/Hr )
Coke - 800#/Hr - Removed at the Coke Filter

| | $Li_2CO_3$ | $K_2CO_3$ | $Na_2CO_3$ | | |
|---|---|---|---|---|---|
| Cost Per Pound | $0.42 | $0.096 | $0.028 | | |
| Makeup Ratio Required for Non-Recovered Salt, #/# of | | | | | |
| Fly Ash and KCl Filter Cake | 0.067 | 0.611 | 0.573 | | |
| Coke Filter Cake | 0.043 | 0.368 | 0.361 | | |
| KCl Produced | - | 0.926 | - | | |
| Annual Replacement for Loss From | | | | | |
| Fly Ash Filter Cake | 93,000# | 843,000# | 791,000# | | |
| KCl Filter Cake | 167,000 | 1,510,000 | 1,417,000 | | |
| Coke Filter Cake | 211,000 | 1,805,000 | 1,771,000 | | |
| KCl Production | - | 2,288,000 | - | | |
| Total | 471,000# | 6,446,000# | 3,979,000# | | |
| Annual Cost for Makeup Due to Losses in | | | | TOTAL | Mills/KWH |
| Fly Ash Filter Cake | $ 39,000 | $ 81,000 | $ 22,000 | $142,000 | 0.029 |
| KCl Filter Cake | 70,000 | 145,000 | 40,000 | 255,000 | 0.052 |
| Coke Filter Cake | 89,000 | 173,000 | 50,000 | 312,000 | 0.064 |
| KCl Production | - | 220,000 | - | 220,000 | 0.045 |
| Total | $198,000 | $619,000 | $112,000 | $929,000 | 0.190 |
| Mills/KWH | 0.041 | 0.126 | 0.023 | 0.190 | |

reduced melt in the coke filter. The unreacted coke could possibly act as an admix and aid in filtration. However, serious problems may result in the reducer quench system due to solubility of the fly ash in the melt at the elevated reducer temperature and its subsequent precipitation at the lower temperature of the reducer quench system. A benefit of this approach could be the possible rupturing of hollow sphere fly ash particles in the reducer which may minimize the amount of melt retained with the fly ash cake if it were filtered with the coke. These variations must be determined from actual pilot plant test work. The fly ash and coke filters are the subject of a discussion in Section 5, Paragraph e.

If the KCl were removed from the process in a form other than a solid, the melt losses would be reduced. It is possible that some, if not all, the KCl will be vaporized in the reducer and be rejected with the oxidizer off-gas stream returning to the boiler. The amount vaporized will depend on its vapor pressure and solubility in the melt at the operating conditions of the reducer. This would reduce or eliminate the melt losses associated with the KCl filter cake. However, the actual location in the process where the KCl is removed must be determined in a pilot plant program.

No test data are available on melt loss associated with coke filtration. It is believed that it will be less than that found with fly ash filtration. An arbitrary value of 50 percent melt contained in the cake has been used for the analysis which must be confirmed by test work.

Delayed petroleum coke has been selected as the source of carbon for reduction (See Section 6, Paragraph e). This material and fluidized petroleum coke, an alternate source of carbon, contain heavy metals, such as vanadium and nickel in amounts ranging up to 2000 ppm. No test data are available on where these heavy metals will concentrate. It has been assumed that this will occur in the unreacted coke which must be filtered and discarded resulting in a substantial melt loss.

If the heavy metals do not concentrate in the unreacted coke, the coke filter cake can be recycled to the process eliminating the carbonate makeup to compensate for the loss, but the heavy metals will have to be removed somewhere else from the process by some other means.

The amount of unreacted coke to be filtered (i.e. 800#/Hr) is based on complete (100%) oxidation of carbon in the coke to provide the reducer sensible heat and heat of reduction. A conversion of 95% of the $M_2SO_4$ to $M_2S$ by carbon is assumed resulting in the 800#/Hr of material to be filtered. An alternate to providing the reducer heat by carbon oxidation is to assume oxidation of $M_2S$ to $M_2SO_4$ resulting in a greater recirculation of $M_2SO_4$ to the reduction zone. This requires more coke for reduction and perhaps 50 percent more unreacted material to be filtered. The actual amount may fall somewhere between these two limits and must be determined by a pilot plant program. The increased coke filtration resulting in an increase in melt loss has not been considered in the evaluation because of:

1. The arbitrary nature of selecting the melt content of the coke filter cake, and

2. the assumption that the cake must be discarded due to the rejection of heavy metals.

The carbonate makeup costs presented in Table 5-1 are arbitrary due to the lack of sufficient test data to establish a basis for analysis. Pilot plant work is definitely dictated to establish a firm basis for evaluation.

If the pilot plant work can demonstrate a reduction in the melt content of the fly ash filter cake it may change the justification for a 99.5 percent efficient electrostatic precipitator and a lithium carbonate recovery process.

Decreasing the melt loss with the coke filter cake may also affect the decision to include the lithium carbonate recovery process.

The use of salts other than carbonate for makeup should be investigated. Potassium sulfate is less expensive than the carbonate and could possibly be added at an appropriate point in the process.

g. Carbonate Recovery

1. Lithium Carbonate Recovery

The justification for a lithium carbonate recovery process is described in Section 6, Paragraph f. However, its justification may not be valid if melt losses can be reduced in the fly ash and coke filtration steps (See Section 5, Paragraph f). The process will have to be developed to determine recovery data and design parameters.

2. Potassium and Sodium Carbonate Recovery

The potassium and sodium carbonate makeup requirements are listed in Table 5-1 of Section 5, Paragraph f. Except for $K_2CO_3$ needed to react with chlorides, the makeup requirements are arbitrary due to the nature of the assumptions of the melt losses.

In all evaluations, it has been assumed that the potassium and sodium salts are not recovered after the aqueous lithium carbonate recovery process because:

1. The fly ash filter cake contains the KCl which is soluble along with the other potassium and sodium salts, and

2. The coke filter cake contains the heavy metals which are removed along with the soluble potassium and sodium salts.

The discarded sodium and potassium salts are mixtures of carbonates, sulfites, sulfates, and sulfides in addition to the potassium chloride.

The annual cost for $K_2CO_3$ makeup to compensate for the mixed salt loss, excluding that required to react with the chlorides, is \$399,000; for $Na_2CO_3$, it is \$112,000. With a capitalization charge of 14 percent, over \$3 million can be spent for a process plant to recover potassium and sodium salts.

Ion exchange is a possible process for removal of the chlorides reporting with the fly ash filter cake. The remaining salts can be recovered by evaporation using the waste heat available in the Molten Carbonate Process. The recovered salt can be analyzed for its constituents and fresh sodium, potassium and lithium carbonate added to prepare the proper ratio of the eutectic for recycle to the Molten Carbonate Process. The effect of any soluble heavy metals on ion exchange will have to be determined by test work. The justification for a process to recover potassium and sodium salts will have to be evaluated after pilot plant work establishes melt composition and losses.

The salts that are discarded may result in a water pollution problem. Recovery may be necessary to minimize this potential problem. In this study, it has been assumed that the salts are discarded with the fly ash from the electrostatic precipitator.

### h. Waste Heat Recovery

The Molten Carbonate Process provides substantial sources of heat that must be rejected to maintain the thermal balance of the plant.

To maintain melt at 850°F in the base case plant, approximately 75 million BTU's per hour must be removed (approximately 50 million in the reducer quench system and 25 million in the regenerator coolers). If this heat is valued at 30¢ per million BTU, the annual value of recoverable heat is approximately $138,000.

It is possible that these streams could be cooled by a portion of the boiler flue gases exiting the air heater (approximately 350°F). The boiler flue gases could be reheated to a temperature of 600-650°F and be returned to the air heater section of the boiler for recovery of the waste heat. This scheme was not considered in the evaluation because of the plan to separate the Molten Carbonate Process from Power Plant operations.

An alternate to this scheme is to reject the process heat to a lower freezing point cooling medium, such as DuPont Hi Tec, and recover the heat from the medium by generation of low pressure steam. This too was not considered because there is no need for low pressure steam in the process except at the Regenerator and this was presumed to be available from the waste heat boiler in the Claus Plant. The power plant would probably have no need for any low pressure steam.

Steam can be generated directly by using waste heat boilers to cool the process melt. However, in order to reduce the possibility of freezing the melt, high pressure boilers are needed; and it is questionable whether this high pressure steam would be at a pressure satisfactory for use in the Power Plant.

Air cooled exchangers were selected for use in the capital cost evaluation for ease in control and low capital cost. These exchangers are bare tube units with external air bypassing to minimize the possibility of freezing the melt. They do not recover waste heat.

The recovery of waste heat from the process by some alternate scheme must be thoroughly evaluated at the time the process is considered for installation in a power plant or smelter.

### i. Integration into Existing Power Plants

In existing coal-fired power plants, a low temperature electrostatic precipitator is generally located after the air heater. In order to integrate the Molten Carbonate Process into existing plants the flue gases must be reheated to the absorber temperature or alternatively withdrawn from before the economizer and a new high temperature electrostatic precipitator installed.

In most power plants, space is at a premium and it will be difficult to install a large size duct to feed a new high temperature precipitator. The problem is compounded because a return duct from the absorber to the boiler will also be required.

The breechings into most boilers can be accommodated by making modifications to the boiler internals. The return of fly ash free flue gas to the boiler will permit smaller extended surfaces to be used for the economizer and air heater sections rather than bare tube sections. A boiler manufacturer has estimated that this modification including breechings, but excluding ductwork will cost $1,000,000 and take ten weeks to install.

A comparison of the costs of integrating the Molten Carbonate Process into an existing hypothetical 800 MW power plant is presented in Table 5-2. The data are based on the results of the investigation on "The Optimum Location of the Electrostatic Precipitator in the Process" (Section 6, Paragraph a).

The capital costs include the new high temperature electrostatic precipitator, modification of the boiler to accommodate the large breechings, and the indirect exchanger to retain the existing low temperature electrostatic precipitator. It excludes:

1) the combustion chamber for the retention of the existing low temperature precipitator because vendors of this type of equipment declined to provide estimating prices.

## Table 5-2. Comparative Cost for Integration into Existing Power Plant

| | Existing Low Temperature Precipitator (99.5% Efficient) | New High Temperature Precipitator (99.5% Efficient) |
|---|---|---|
| Precipitator | Existing, assumed to be amortized | 3,240,000 |
| Indirect Exchanger Installed Cost excluding Combustion Chamber | 1,950,000 | |
| Boiler Modifications | - | 1,000,000 |
| Total | 1,950,000 | 4,240,000 |
| Annual Costs | | |
| Capitalization Charge | 273,000 | 594,000 |
| Power for Precipitator | 90,000 | 149,000 |
| Power for Indirect Exchanger Pressure Loss | 128,000 | - |
| Fuel for Reheat (100°F Rise) | 429,000 | - |
| Total Comparative Annual Cost | 920,000 | 743,000 |

2) ductwork costs.

3) modification or new boiler fans to overcome increased pressure loss.

4) fly ash disposal equipment for the new high temperature precipitator. It is assumed that this equipment can be salvaged from the abandoned low temperature precipitator.

5) scrap and salvage value of the low temperature precipitator if a new high temperature unit was installed.

The operating cost excludes:

1) capitalization charge for the existing low temperature electrostatic precipitator. It is assumed to be amortized.

2) power required to overcome the combustion chamber pressure drop if the existing precipitator were retained.

3) plant downtime to make internal boiler modifications or connections to a reheat system.

For the hypothetical case, the installation of a new high temperature precipitator results in a lower annual cost. However, the integration of the Molten Carbonate Process using this method into existing power plants will depend on the space available in the plant and, the ability to make the necessary boiler modifications. Each plant must be individually analyzed for the best way to integrate the process.

### j. Copper Smelter

The Molten Carbonate Process shows promise for removal of $SO_2$ from copper smelter reverberatory furnace flue gases. It has not been considered for use with roaster off-gases because of the high $SO_2$ content of the gases which can be utilized in a conventional contact acid plant. The process has not been considered for removal of $SO_2$ from converter off-gases in this study. The converter operations are of a cyclic nature and some smelters stagger the blow of the converters to reduce the cycling so that the gases can be fed to an acid plant. However, it is possible that the process can be applied to such a cyclic process where the gas flow and $SO_2$ concentration varies by designing the absorber system for the extreme gas condition and the remainder of the process for an average melt flow. Additional melt surge capacity may be required as a "fly wheel" to compensate for the $SO_2$ variation in the gas feed.

The location in the reverberatory furnace process scheme where the off-gases should be withdrawn for removal of $SO_2$ will depend on the actual plant under consideration. If the gases are taken for removal of $SO_2$ after an existing low temperature bag house or electrostatic precipitator then they will have to be reheated to absorber temperature. Alternately, the gases may be taken after the waste heat boiler operating at 800-850°F and sent through a new high temperature electrostatic precipitator. The point at which the gases should be withdrawn and how they should be treated to provide the necessary absorber temperature is discussed in Section 6, Paragraph g.

The problems that may be encountered in the Molten Carbonate Process if it were applied to a copper smelter are essentially those that would be encountered in the power plant case discussed in previous paragraphs of this section of the report. The basic difference between the two, other than $SO_2$ concentration, is in the contaminants in the gases that are to be treated.

Besides a higher $SO_2$ content of the reverberatory furnace off-gas, these gases may contain fluorides which may react differently from the chlorides present in power plant stack gases. The effect of this contaminant on the process must be determined.

Another contaminant present in the gases is the heavy metals in the fume and particulate matter that is not collected in the bag house or electrostatic precipitator. If these are absorbed in the process melt they will have to be removed at the point where they concentrate. This may be at the filter after the absorber (termed "the fly ash filter" in the power plant case) or at the coke filter, or elsewhere.

The particulate matter that is not removed in the bag house or electrostatic precipitator is different from power plant fly ash. Tests would be necessary to determine its filtration characteristics if it had to be filtered.

The effect of these contaminants on the Molten Carbonate Process would have to be determined in a pilot plant program utilizing actual smelter gases.

## 6. ECONOMIC STUDIES

Various economic studies (tradeoffs) were performed to

(1) select the optimum equipment or process scheme,
(2) evaluate the necessity for a process operation, such as lithium carbonate recovery, and
(3) establish the lowest cost raw material, such as the type of coke to use for reduction.

The results of a pilot program may establish the need for additional tradeoff studies. Anticipated future studies are:

1. Recovery of waste heat from process melt or gases in a fully integrated plant consisting of Power Plant or Copper Smelter, Molten Carbonate Plant, Lithium Carbonate Recovery Plant and a Claus Plant (see Section 5, Paragraphs c and h).

2. Recovery of sodium and potassium salts from waste streams presently discarded (see Section 5, Paragraphs g).

The economic evaluations performed for this study are contained in this section of the report. All evaluations unless otherwise stated assumed the following:

a. base case power plant of 800 MW capacity burning coal containing 3 percent sulfur and 0.04 percent chlorides and operating at a 70 percent plant factor.

b. an annual capitalization charge of 14 percent of the installed cost.

c. Utility Costs

Fuel - \$0.04/million BTU
Steam - \$0.05/million BTU from the power plant

Steam was assumed available from the Claus Plant at no charge. No credit to be allowed for export of steam.

Power - 6 mills/KWH

Other assumptions relating to the specific evaluation are indicated for each subject.

### a. Optimum Location of the Electrostatic Precipitator in the Process

Current practice for removal of fly ash in coal-fired power plants is to locate an electrostatic precipitator operating at about 300°F after the air heater. At this temperature it will be necessary to reheat the gases to obtain the required 850°F operating temperature of the absorber in the Molten Carbonate Process.

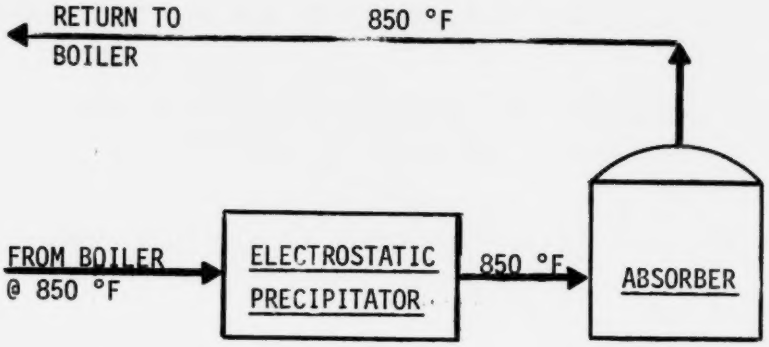
To eliminate reheat, high temperature gases can be removed from an appropriate point in the boiler and directed through an electrostatic precipitator before being sent to the absorber.

An evaluation was performed to compare the cost of a high temperature electrostatic precipitator to a low temperature electrostatic precipitator at different efficiencies.

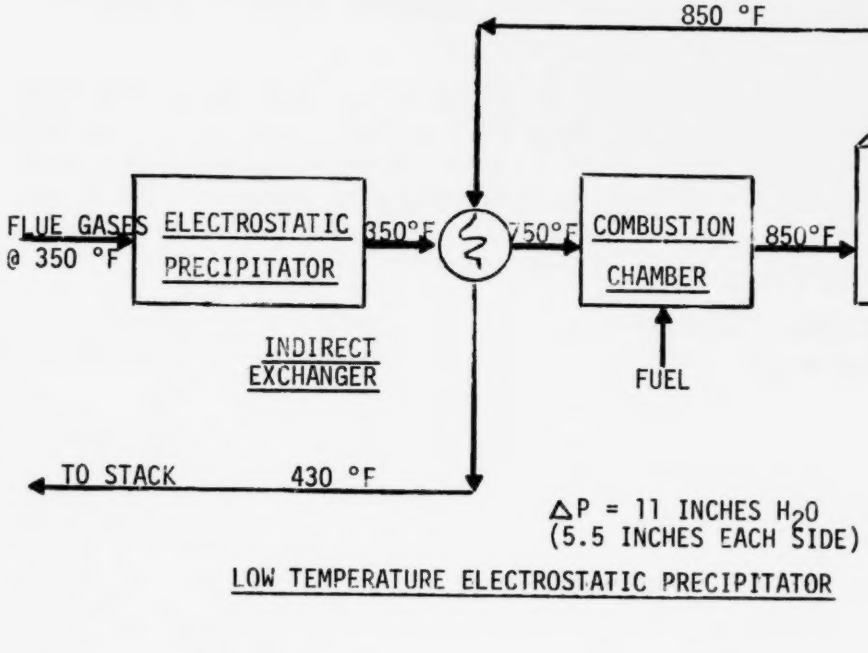
In the high temperature case, flue gases are removed from the boiler before the economizer at a temperature of 850°F. The gases pass through the electrostatic precipitator to the absorber and are returned to the boiler at the economizer. The temperature of the gases at any withdrawal point in the boiler will vary depending on the load. It may be necessary to provide facilities at the boiler to overcome serious temperature fluctuations that may affect the absorber. These facilities are beyond the scope of this study and have not been considered.

The process schemes for the above precipitator locations are shown in Figure 6-1.

FIGURE 6-1. ELECTROSTATIC PRECIPITATOR LOCATION


RETURN TO
BOILER
850 °F
FROM BOILER
@ 850 °F
ELECTROSTATIC
PRECIPITATOR
850 °F
ABSORBER

HIGH TEMPERATURE ELECTROSTATIC PRECIPITATOR


850 °F
FLUE GASES
@ 350 °F
ELECTROSTATIC
PRECIPITATOR
350°F
750°F
COMBUSTION
CHAMBER
850°F
ABSORBER
INDIRECT
EXCHANGER
FUEL
TO STACK
430 °F
ΔP = 11 INCHES $H_2O$
(5.5 INCHES EACH SIDE)

LOW TEMPERATURE ELECTROSTATIC PRECIPITATOR

Estimated equipment costs for the two cases were obtained from vendors and utility cost estimates were calculated from data provided by the vendors.

The evaluation of capital costs include only the electrostatic precipitator and indirect exchanger for the low temperature case. It excludes:

1) The combustion chamber for the low temperature case because vendors of this equipment declined to provide estimating prices.

2) Increased costs for larger ductwork in the high temperature case which may be offset by more extensive ductwork in the low temperature case.

3) Increased cost of large size boiler breechings in the high temperature case which may be offset by the reduced cost of the boiler economizer and air heater because of the return of clean flue gas.

4) Precipitator fly ash disposal equipment which will be the same for both cases.

The operating costs for the low temperature case exclude the power required to overcome the combustion chamber pressure drop.

The evaluation, summarized in Table 6-1, clearly shows that the high temperature electrostatic precipitator results in a lower annual cost. The excluded items listed above economically favor the low temperature electrostatic precipitator scheme. As a result, the high temperature electrostatic precipitator has been used in the study of the overall process.

A further study was performed to determine the optimum efficiency of the precipitator. This study is discussed in Section 6, Paragraph b.

Table 6-1. Comparative Costs for Location of Electrostatic Precipitator

| | Low Temperature (325°F) | | | High Temperature (850°F) | | |
|---|---|---|---|---|---|---|
| | Efficiency | | | Efficiency | | |
| | 99 | 99.5 | 99.9 | 99 | 99.5 | 99.9 |
| Precipitator Installed Cost | $1,640,000 | $1,980,000 | $2,740,000 | $2,672,000 | $3,240,000 | $4,448,000 |
| Indirect Exchanger Installed Cost excluding Combustion Chamber | 1,950,000 | 1,950,000 | 1,950,000 | - | - | - |
| Total Installed Cost | $3,590,000 | $3,930,000 | $4,690,000 | $2,672,000 | $3,240,000 | $4,448,000 |
| Electrostatic Precipitator Power Requirements, KWH | 2,070 | 2,440 | 3,650 | 3,470 | 4,050 | 4,700 |
| Indirect Exchanger Pressure Loss, in $H_2O$ | 11 | 11 | 11 | - | - | - |
| Reheater Fuel Requirements, Million of BTU/Hr. | 175 | 175 | 175 | - | - | - |
| Annual Costs,$ | | | | | | |
| Capitalization Charge | 503,000 | 550,000 | 657,000 | 374,000 | 454,000 | 623,000 |
| Power for Precipitator | 76,000 | 90,000 | 134,000 | 128,000 | 149,000 | 173,000 |
| Power for Indirect Exchanger Pressure Loss | 128,000 | 128,000 | 128,000 | - | - | - |
| Fuel for Reheat (100°F Rise) | 429,000 | 429,000 | 429,000 | - | - | - |
| Total Comparative Annual Cost | $1,136,000 | $1,197,000 | $1,348,000 | $502,000 | $603,000 | $796,000 |

### b. Electrostatic Precipitator Efficiency & Penalties

The efficiency of the electrostatic precipitator controls the amount of fly ash that is carried with the flue gases to the absorber. The fly ash which is not removed in the precipitator is removed in the absorber by the molten carbonate and is subsequently filtered and discarded from the melt before the reduction step.

The fly ash filtration tests carried out by Atomics International used a wedge wire-wound filter element of 25 micron spacing. They showed that the filter cake contains 65 percent melt and 35 percent fly ash.

A study was performed to determine the optimum efficiency of the high temperature electrostatic precipitator to minimize the costs associated with melt loss in the fly ash filter cake.

The evaluation was based on the following assumptions:

1. The filter provides a dry cake discharge - i.e. no melt is carried along with the fly ash greater than the 65 percent melt content of the filter cake.

2. Chlorides present in the flue gas reacts with $K_2CO_3$ to form KCl which is slightly soluble in the melt. The insoluble KCl is removed from the process with the fly ash filter cake. Therefore, filter installed costs were not considered for fly ash removal since a substantial portion of its cost is attributable KCL filtration. The melt loss associated with KCL content of the fly ash filter cake was not considered in evaluating the efficiency of the electrostatic precipitator since it would be a constant at the different efficiencies.

3. Lithium salts can be partially recovered from the discarded filter cake in an aqueous process as presently conceived under the following conditions:

(a) soluble lithium salts react with soluble carbonate salts to form insoluble lithium carbonate.

(b) twelve percent of the insoluble lithium carbonate cannot be recovered in the process.

(c) delivered cost for $Li_2CO_3$ - $0.42 per pound.

4. All sodium and potassium salts are lost in the aqueous lithium carbonate recovery process as presently conceived. Delivered cost for replacing the salts are:

$K_2CO_3$ - $0.096 per pound.

$Na_2CO_3$ - $0.028 per pound.

The results of the tradeoff study for four high temperature precipitator efficiencies are summarized in Table 6-2. The least annual cost unit falls somewhere above the 99 percent efficiency with 99.5 percent being the lowest of the four cases studied.

For purposes of the process evaluation, the 99.5 percent efficient high temperature electrostatic precipitator has been selected as the basis for comparison to precipitator equipment normally found in a power generating station without an $SO_2$ re covery process.

Existing power plants generally have located the precipitator in the flue gas stream after the air preheater. Consolidated Edison's Ravenswood No. 30 unit is an exception to this rule. Selection of the efficiency of the precipitator is based on existing local codes and no general rule can be applied to define the typical efficiency. It is very likely that power plants will be faced with more stringent fly ash control in the future. An efficiency of 99 percent for a low temperature electrostatic precipitator in a power plant without an $SO_2$ recovery system has been selected as the basis for determining the penalty that must be applied to a 99.5% efficient high temperature precipitator when installed in a power plant burning 3 percent sulfur in coal. Table 6-3 compares these costs and lists a $1,600,000 capital cost penalty that has been applied to the Molten Carbonate Process for use of the more efficient and higher temperature electrostatic precipitator that the process requires.

At high electrostatic precipitator temperatures, the resistivity of the dust in the flue gases is not affected by the $SO_2$ content in the gas and the size, price, and power requirements of a precipitator are the same for the same efficiency. This is not the case at lower temperatures. A larger size unit is required for a low temperature precipitator in a power plant burning coal containing one percent sulfur than is required for burning coal containing three or six percent sulfur at the same efficiencies.

Table 6-2. Melt Losses Attributable to Electrostatic Precipitator Efficiency

| | Precipitator Efficiency | | | |
|---|---|---|---|---|
| | 95 | 99 | 99.5 | 99.9 |
| Precipitator Installed Cost | $2,000,000* | $2,672,000 | $3,240,000 | $4,448,000 |
| Precipitator Power Requirements, KW | 1,600 | 3,470 | 4,050 | 4,700 |
| Fly Ash to Filter, #/Hr. | 2,250 | 450 | 225 | 45 |
| Equivalent Carbonate Losses, #/Year | | | | |
| $Li_2CO_3$ (0.067 #/# fly ash | 925,000 | 185,000 | 93,000 | 19,000 |
| $K_2CO_3$ (0.611 #/# fly ash) | 8,430,000 | 1,686,000 | 843,000 | 169,000 |
| $Na_2CO_3$ (0.573 #/# fly ash) | 7,906,000 | 1,581,000 | 791,000 | 158,000 |
| Annual Costs, $ | | | | |
| Capitalization Charge | 280,000 | 374,000 | 454,000 | 623,000 |
| Power | 59,000 | 128,000 | 149,000 | 173,000 |
| $Li_2CO_3$ Replacement | 389,000 | 78,000 | 39,000 | 8,000 |
| $K_2CO_3$ Replacement | 809,000 | 162,000 | 81,000 | 16,000 |
| $Na_2CO_3$ Replacement | 221,000 | 44,000 | 22,000 | 4,000 |
| Total Annual Cost: | $1,758,000 | $786,000 | $745,000 | $824,000 |

* Based on A.I. Data

## Table 6-3. Molten Carbonate Process Electrostatic Precipitator Penalty

| | Precipitator | | |
|---|---|---|---|
| | Low Temperature 99% | High Temperature 99.5% | Penalty |
| Precipitator Installed Cost | $1,640,000 | $3,240,000 | $1,600,000 |
| Power Consumption KW | 2,070 | 4,050 | 1,980 |
| Annual Cost, $ | | | |
| Capitalization Charge | 230,000 | 454,000 | 224,000 |
| Power Cost | 76,000 | 149,000 | 73,000 |
| Total Annual Cost | 306,000 | 603,000 | 297,000 |
| Mills/KWH | 0.062 | 0.123 | 0.061 |

Table 6-4 lists the estimated installed costs obtained from an electrostatic precipitator vendor for units in an 800 MW plant operation at different efficiencies with 1,3 and 6 percent sulfur in coal. These prices were used for determination of the panalties to be applied to the alternate power plant cases.

### c. Absorber-Size, Number, Configuration

The absorber is the key element in the Molten Carbonate Process, for it is here that the sulfur dioxide in the flue gas is scrubbed with the circulating molten salts.

Atomics International has expended a good deal of effort on experimentation in this area, and came to the conclusion that a spray tower where the superficial gas velocity is 25 feet per second and an average droplet size of 100 microns will give a sulfur dioxide removal efficiency above 95 percent.

We have selected four absorbers, one per electrostatic precipitator. It is possible to design for two (or maybe even one) absorber, but we have selected four for the following reasons:

1. Duct manifolding becomes complex if there are fewer absorbers than precipitators.

2. Absorber diameters become quite large if the number is less than four.

3. One absorber per electrostatic precipitator gives adequate scrubbing ability if one absorber is out of service.

The diameter of each of the four absorbers, based on the superficial gas velocity being maintained at 25 ft/sec. is 28' -6".

The straight height has been estimated at 34 feet, made up as follows:

2' clearance at bottom.
11' size of gas inlet connection.
15' active section, to inlet spray nozzles.
3' from spray nozzles to top of demister.
3' top clearance.

Table 6-4. Estimated Installed Cost of Electrostatic Precipitators for 800 MW Power Plant

| Temperature, °F | S in Coal, % | Efficiency, % | Estimated* Installed Cost, $ |
|---|---|---|---|
| 350 | 1 | 99 | 2,700,000 |
| 350 | 1 | 99.5 | 3,280,000 |
| 350 | 1 | 99.9 | 4,200,000 |
| 350 | 3 | 99 | 1,640,000 |
| 350 | 3 | 99.5 | 1,980,000 |
| 350 | 3 | 99.9 | 2,740,000 |
| 350 | 6 | 99 | 1,520,000 |
| 350 | 6 | 99.5 | 1,920,000 |
| 350 | 6 | 99.9 | 2,680,000 |
| 850 | 1,3,6 | 99 | 2,672,000 |
| 850 | 1,3,6 | 99.5 | 3,240,000 |
| 850 | 1,3,6 | 99.9 | 4,448,000 |

* Excludes - ductwork and fly ash removal equipment.

Type 347 stainless steel has been selected as the material of construction, with an allowance for 5" of external insulation. This method of construction is ideal from a process standpoint, since 347 SS is corrosion resistant to melt below 1000°F and the use of external, low conductivity insulation minimizes the heat loss. However, the cost of an all 347 SS unit is quite high, so other possible construction methods were examined.

In general, whenever one speaks of a costly stainless steel piece of equipment, one is tempted to try using carbon steel with a stainless steel cladding. This approach will not work here since, with external insulation, the metal temperature will approach melt temperature, which would be, as a design value, 950°F. At such temperatures, the stress value of low carbon steel, or low alloy steel, is too low.

Stainless clad steel construction was considered but rejected since the allowable stress in the carbon steel section at 950°F is so low as to force the use of a very heavy steel plate.

The next approach is to find a lining material which will reduce the metal temperature to the acceptable range for carbon steel. The ideal substance to use would be a low thermal conductivity material such as that used for external insulation. Unfortunately, there are, at present no known low thermal conductivity insulating materials which are compatible with the lithium carbonate - sodium carbonate - potassium carbonate melt.

A high alumina brick, such as Alundum, is compatible with melt, but has a relatively high thermal conductivity. The low condictivity insulation cannot be used in conjunction with the Alundum for the following reasons:

1. If the insulation is external, (melt-Alundum-metal-insulation) the metal temperature will be too high for carbon steel.

2. If the insulation is internal, (melt-Alundum-insulation-metal) the melt can be expected to seep through voids in the Alundum, and come into contact with the insulation with which it is not compatible.

This situation is similar to the reducer, as discussed in Section 6, Paragraph d.

The alternate to an all 347 SS unit, then, is a carbon steel or low alloy steel vessel, lined internally with Alundum only. A 9" layer of Alundum was investigated as a lining in a vessel with a low alloy steel shell and floor. Type 347 SS was selected for the roof because of anticipated problems with brick lining. The diameter of metal shell was 30' to maintain a 28' -6" inside diameter for gas velocity considerations.

An absorber constructed in this manner has a much greater heat loss than an all 347 SS unit with external insulation - 4,000,000 BTU/hr. vessel vs. 407,000 BTU/hr. per vessel. In calculating comparative annual costs for the two methods of construction, it has been assumed that the difference in heat loss would be evident at the power plant, and a value of $.30/million BTU was allowed.

Table 6-5 lists the comparative costs of the two types of absorbers and shows that the units constructed of Type 347 SS are less expensive.

There are also problems of a practical nature associated with theAlundum lined case. As pointed out previously, external insulation cannot be used in this case, and the metal temperature would be about 400°F. This is a dangerous situation, and great care would have to be exercised in the design of stairs, operating platforms, connections, etc.

In the Alundum lined case, about 10% of the capital cost can be saved if low alloy steel is replaced by low carbon steel. This would not be enough to change the conclusion. Furthermore, it is questionable whether it would be sound to use low carbon steel here, since localized hot spots could cause the metal temperature to be too high for low carbon steel.

d. Reducer - Size, Number and Configuration

The basic parameters for design of the reducers are:

Liquid Retention Time - 20 minutes
Static Depth of Melt - 2-3 feet
Superficial Gas Velocity - 3 FPS
Bed expansion - 100% maximum

## Table 6-5. Absorber Costs

| Case | A) Low Alloy Steel w/9" Alundum Internal Lining | B) 347 SS w/5" External Insulation |
|---|---|---|
| Cost of Metal. per unit | $136,000 | $305,000 |
| Cost of Alundum, per unit | 220,000 | - |
| Cost of Insulation per unit | - | 27,000 |
| Total Cost, per unit | $356,000 | $332,000 |
| Annual Charge, per unit | 50,000 | 47,000 |
| Annual Value of Heat Loss, per unit | 7,000 | 1,000 |
| Comparative Annual Cost, per unit | $57,000 | $48,000 |
| Comparative Annual Cost, 4 units | $228,000 | $192,000 |

Calculations of the vessel sizes required to accomplish the above design parameters were performed for various multiple units of vertical and horizontal vessels. For each of the multiple horizontal units, the lengths were kept constant at a nominal 20' and the diameter calculated to give the required retention time and superficial gas velocity.

In calculating vertical units, the height was kept constant at 6', and the diameter changed to maintain the required residence time and gas velocity.

In comparing the costs of the same number of vertical units to the same number of horizontal units, the vertical case always results in a significantly higher cost. This is due, primarily, to the fact that vertical units have very large diameters, compared to horizontal units and the thickness of the vessel shell required to contain the pressure is substantially greater. For example, if 4 vertical units were used instead of 4 horizontal units, the diameters would be 18'-6" instead of 11'-0", and the total weight of 4 units would be about 135,000 lb. instead of about 50,000 lb. On this basis it was decided to evaluate horizontal vessels for use in the reduction step.

Several cases for horizontal vessels were evaluated, the variable being the number of units. As the number of units decreases, the diameters, of course, increase. The total cost of the units themselves remains about the same as the number is decreased. However, the overall cost of the installation decreases as the number of units is decreased. This is because there are fewer foundations, less piping, etc.

Four horizontal vessels were selected because with this quantity the calculated diameters are 11'-0" which approaches the limit for rail shipment and permits the vessels to be shop fabricated. It is desired to avoid, where possible, larger diameter vessels and the need for field fabrication.

The design temperature of the melt is 1500°F. Many materials of construction were studied, bearing in mind the following considerations:

1. A fused cast alumina product, such as Monofrax, withstands melt at 1500°F.

2. A high alumina insulating material, such as Alundum can be used as back-up to the Monofrax.

3. 347 stainless steel is corrosion-resistant to melt below 1000°F.

4. Silica containing insulation products are not suitable against melt.

5. Carbon steel or low alloy steel is corrosion-resistant to frozen melt.

The selection of Monofrax in contact with melt is based on work performed by Atomics International. The selection of the less expensive Alundum as back-up will have to be confirmed.

The first reducer construction method investigated was the "skull" or cold wall concept in which sufficient heat is removed from the reducer by an external cooling jacket to cause a thin layer, or "skull", of melt to freeze at the surface. This frozen layer of melt protects a metal vessel wall. This method would work if the inside coefficient of heat transfer were low. However, in an article called Designing Gas-Sparged Reactors by J.R. Fair (2), it is reported that inside coefficients in sparged vessels have been found to be very high, even with relatively low gas flows. In the reduction step under consideration, air is provided to oxidize the $M_2S$ to $M_2SO_4$ and $CO_2$ is produced by the reduction of $M_2SO_4$ with carbon. Applying the experience of this article to the design conditions of the reducer result in an inside coefficient of heat transfer on the order of 1000 Btu/hr-$ft^2$ -°F.

This high heat transfer rate makes the "skull" concept impractical because of the large amount of heat to be transferred which must be replaced by burning coke. The heat to be transferred can be calculated as follows:

The effective area for heat transfer, in the liquid phase is approximately 350 square feet for a reducer 11' diameter x 20' long (based on inside of brick dimensions). If a skull exists, it implies that a freezing temperature of approximately 750° has been attained. Therefore, the amount of heat transferred from melt (at 1500°F) to skull (at 750°) would be (1500-750) (1000)(350) = 260,000,000 Btu/hr for each of four reducers. This amount of heat would, of course, also have to be transferred out of the vessel, and is much higher than can be tolerated. Furthermore, the quantity of coke needed to maintain the reducer at the operating temperature is not economically practical.

Other methods investigated involved the "hot wall" concept, i.e. non-jacketed vessels with internal insulation. The first of the "hot wall" methods evaluated was a vessel in which 4" Monofrax was used against melt, followed by 4" Alundum 4", silica insulation, and then the metal wall.

This type of configuration gives a low metal temperature (about 200°F) and a low heat loss (about 100,000 Btu/hr per vessel). However, the temperature profile (see Figure 6-2 is not satisfactory) because the freezing point occurs somewhat within the silica layer. Consequently, melt may be in contact with silica insulation because of the probable seepage of melt through Monofrax and Alundum causing attack on the insulation.

It will be seen from Figure 6-2 that Monofrax and Alundum are relatively poor insulators and result in low temperature gradients.

The next "hot wall" approach evaluated, was to use sufficient thickness of Monofrax to lower the metal wall temperature permitting use of carbon steel. With 24" of Monofrax the wall temperature is approximately 500°F and the heat loss per vessel is about 800,000 Btu/hr. This is a satisfactory design to permit use of a carbon steel shell with only Monofrax in contact with melt but the cost of 24 inches of Monofrax lining is high.

If, as has been assumed, the less expensive Alundum can be used as back-up to Monofrax, then another possible method of construction is suggested - a relatively small layer of Monofrax in contact with melt, and then a layer of Alundum.

Figure 6-2. Temperature Profile of Reducer Internally Lined with Monofrax, Alundum and High Silica Insulation

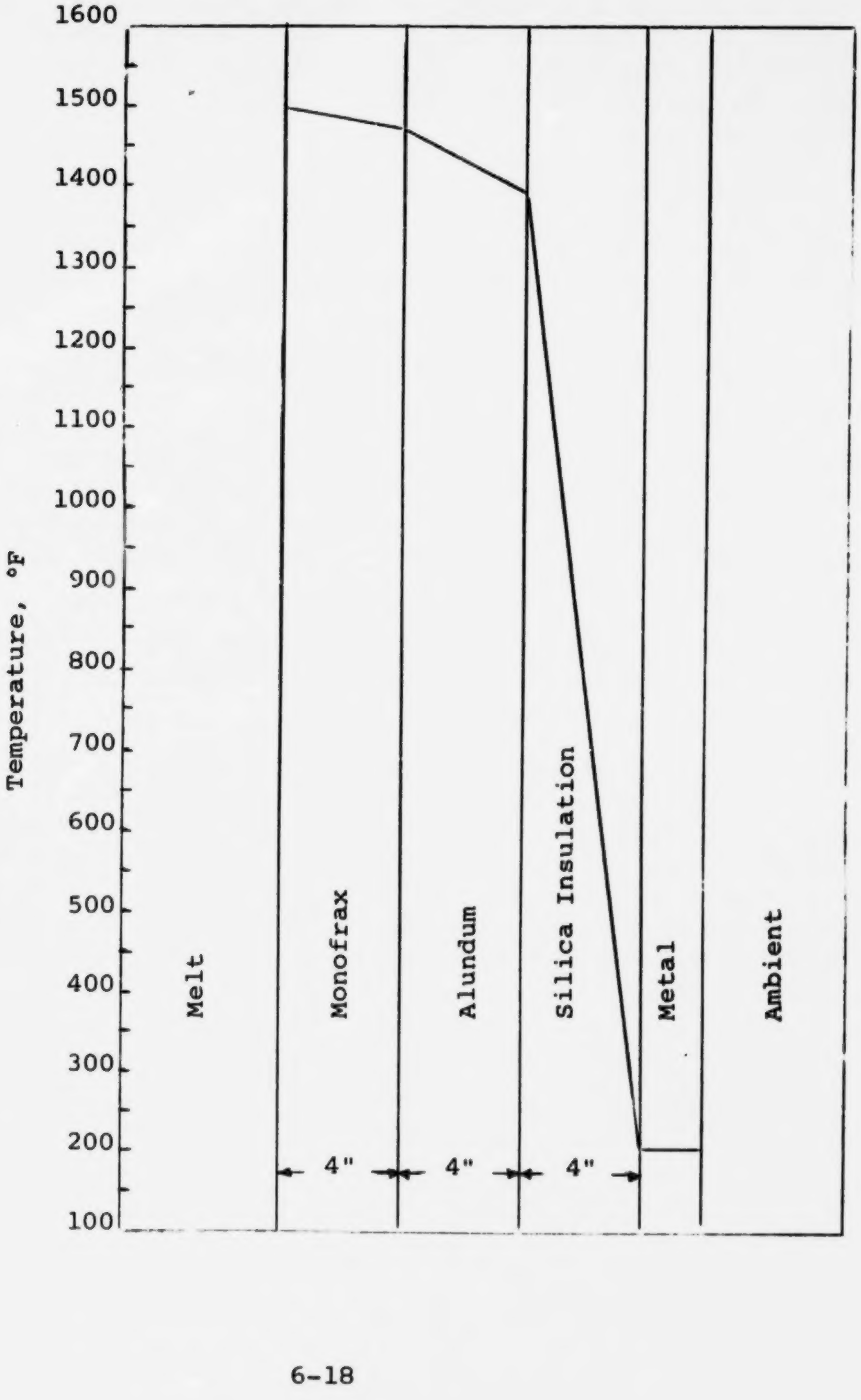
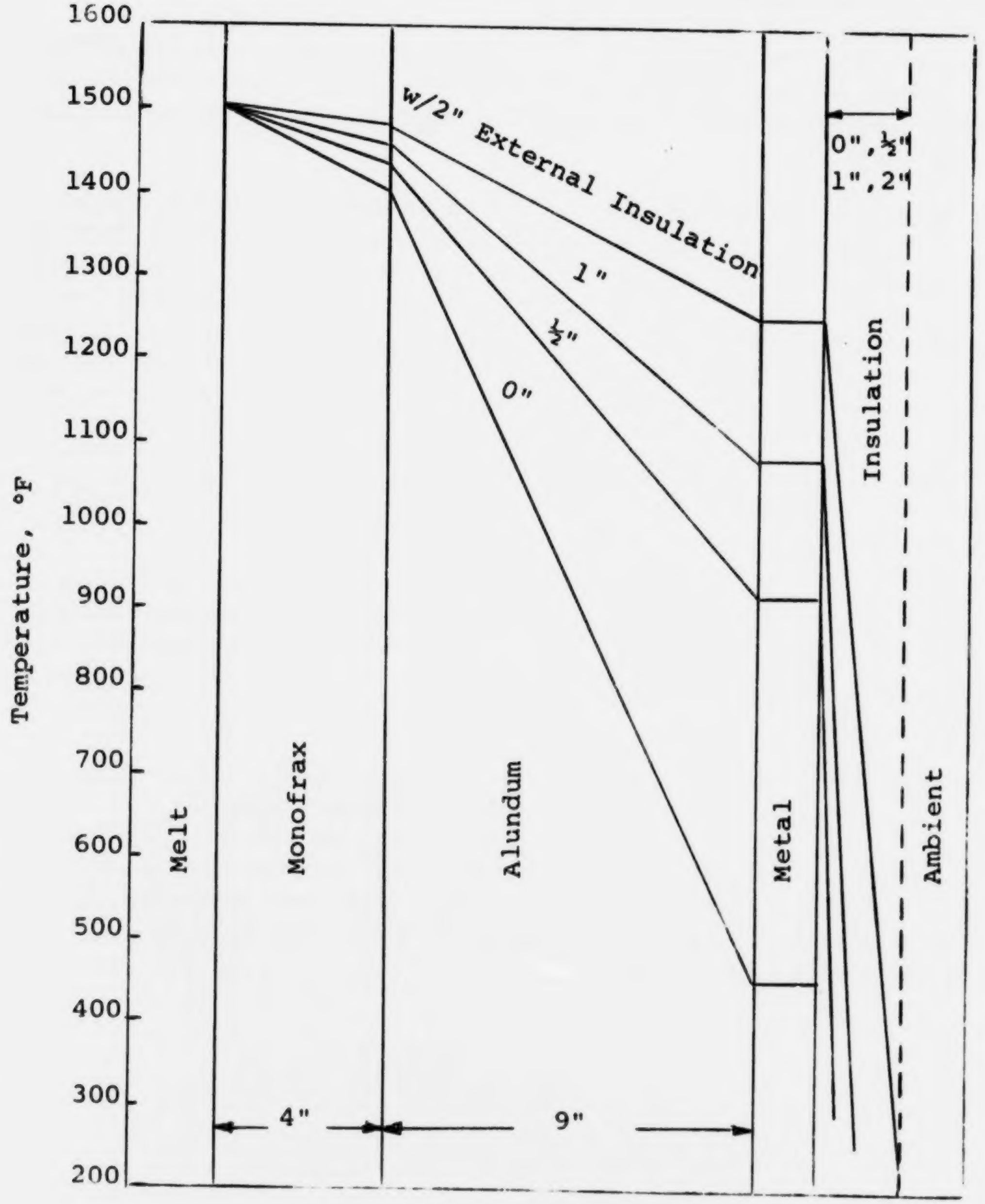


Figure 6-3. Temperature Profile of Reducer Internally Lined With Monofrax and Alundum, With Various Thicknesses of External Insulation



This was evaluated for 4" Monofrax, 9" Alundum, and various thicknesses of external insulation. The temperature profiles are plotted in Figure 6-3 which shows that carbon steel can be used only if no external insulation is used. Thus, we see that a low thermal conductivity insulating material cannot be used as internal or external insulation. If used externally, it raises the metal wall temperature above the range of carbon steel construction. If used internally, it can be expected to come into contact with melt seepage and be attacked. At present, Atomics International are not aware of low thermal conductivity insulating materials which are compatible with the melt at the operating temperature of the reducer.

The proposed construction is for 4" of Monofrax and 9" of Alundum. The material selected for the reducer shell is ASTM A-204, which is a low alloy steel that is somewhat more expensive than low carbon steel, but retains useful stress values up to temperatures of about 900°F. The calculated temperature of about 450°F is within the useful range of carbon steel, but the use of A204 will allow for localized hot spots. (The savings in using low carbon steel instead of low alloy steel is relatively small i.e. in the order of 5-10% of the overall cost of the vessel). The heat loss is expected to be about 550,000 Btu per hour per vessel.

Neither Monofrax nor Alundum are completely free of voids or joints. The possibility of cracks developing in the lining cannot be overruled. The performance of these refractories in freezing and thawing service remains one of the areas for investigation in a pilot plant.

Table 6-6 shows the development of the capital cost comparison for one reducer 11' diameter by 20' which leads to the selection of the "no insulation" case. The Monofrax and Alundum would be present in all the cases, so the cost is not shown. Aside from economic considerations, the last two cases above should be discarded because the melt temperature in contact with the 347 SS is too high.

## Table 6-6. Reducer Construction

| External Insulation | None | ½" | 1" | 2" |
|---|---|---|---|---|
| Metal Temperature, °F | 450 | 950 | 1,120* | 1,270* |
| Outside Temperature, °F | 450 | 300 | 250 | 200 |
| Heat Loss, Btu/Hr | 550,000 | 300,000 | 210,000 | 120,000 |
| Material of Construction | A 204 | 347 SS | 347 SS | 347 SS |
| Cost of Metal | $11,300 | $33,800 | $33,800 | $33,800 |
| Cost of External Insulation | 0 | 1,000 | 1,600 | 2,500 |
| Total Capital Cost | $11,300 | $34,800 | $35,400 | $36,300 |
| **Annual Costs, $** | | | | |
| Capitalization Charge | 1,600 | 4,900 | 5,000 | 5,100 |
| Cost of Coke to off-set Heat loss (based on 14,000 Btu/lb, $11/ton Coke) | 1,400 | 800 | 600 | 500 |
| Comparative Annual Cost | $3,000 | $5,700 | $5,600 | $5,600 |

* Reject due to anticipated corrosion of vessel wall by melt.

### e. Coke-Economic Aspects

In Progress Report No. 3, Atomics International states "that almost any form of carbon can be used as a reducing agent". Several materials were satisfactorily tested as available sources of carbon, and an economic evaluation performed by A.I. indicated that fluidized petroleum coke was the least expensive source of carbon. Green delayed high sulfur petroleum coke was considered as another economically acceptable raw material.

The present-day prices for coke reflect, to some degree, the energy shortage which is now being experienced. Table 6-7 compares the analysis and unit prices of two forms of coke currently available.

In the base case plant, approximately 9 tons of carbon are required per hour to reduce the sulfate to sulfide. This neglects any reducing agent advantage that may occur due to the volatile content of the coke. It further assumes that the heat of combustion of the volatile matter is sufficient to satisfy the increased heat required to vaporize the free water contained in the coke. At a plant factor of 70 percent, the operating cost saving using delayed coke, rather than fluidized coke, amounts to $215,000 per year.

The use of delayed coke presents a minor handling problem that is not present with fluidized coke. In their reduction experiments, Atomics International used "as received" delayed coke of minus ¼ inch. Most delayed coke producers do not screen coke fines from their product, which can be used in the process; but instead sell their material as indicated in Table 6-7 at minus 2 inches with 50% minus ¼ inch. It is possible that this minus 2 inch coke could be used for reduction; however a crushing and screening circuit has been provided in the facilities to prepare material of the size used in the bench-scale work. These additional facilities cost less than $75,000 to install, which is equivalent to an annual cost of $10,500 using 14 percent capitalization charges. This is substantially less than the savings realized by using the delayed coke, thereby justifying its inclusion in the process scheme. If further experimentation proves that the minus 2 inch material can be used, the crushing and screening circuit can be eliminated.

## Table 6-7 Coke Comparison

| | Fluidized Petroleum Coke | Green Delayed High Sulfur Petroleum Coke |
|---|---|---|
| Particle Size | 96+% minus 8 mesh | Minus 2 inch;<br>50% minus ¼ inch |
| Analysis (Dry Basis): | | |
| Inerts | 0.6 wt.% | 0.4 wt.% |
| Sulphur | 7 | 6 |
| Volatile Matter | 6 | 12 |
| Fixed Carbon | 86.4 | 81.6 |
| Water | 1 wt.% | 5-8 wt.% |
| Cost per ton, FOB works | $10.00 | $6.00 |
| Allowance for Freight, per ton | $5.00 | $5.00 |
| Delivered Cost per ton of coke | $15.00 | $11.00 |
| Delivered Cost per ton of carbon | $17.36 | $13.48 |

Tests will be required to determine the effect of the higher volatile and water content of the delayed petroleum coke on the reduction step.

As a result of the above analysis, delayed petroleum coke at a delivered cost of $11.00 per ton has been used as the basis in the operating cost determination; and, the Engineering Flow Diagram - Coke Handling Facilities, Drawing No. PS-218-0003 is the basis for the capital cost of the process.

The continued availability of coke at these price levels will depend on the market demand. Alternate low cost raw materials should be investigated as sources of the carbon required for reduction. Coal is a possible alternate but the ash content will add appreciably to the load on the coke filter and may affect the reducer operation.

### f. $Li_2CO_3$ Recovery Process

The filter cakes from the fly ash and coke filtration steps of the process retain appreciable quantities of melt. Experimental data indicate that the fly ash cake contains 65 percent melt while the coke filter cake has been assumed to contain 50 percent melt.

In prior work, Atomics International describes a theoretical aqueous process in which 88 percent of the lithium carbonate can be recovered. In this study, an estimate has been made of the value of the lithium carbonate that can be recovered by this process and was based on the following assumptions:

1) KCl if formed in the absorber by reaction of the chlorides in the flue gases with potassium salts. Its solubility is 3 percent in carbonate melt and any excess over this solubility is removed with the fly ash in the fly ash filter.

2) The fly ash filter cake, containing the insoluble KCl, has a composition of 65 percent melt and 35 percent solids.

3) The coke filter cake contains the heavy metals and must be removed from the process. It contains 50 percent melt. The coke usage in the reducer and the subsequent unreacted amount to be filtered from the reduced melt is based on coke oxidation rather than $M_2S$ oxidation to provide the reducer sensible heat and heat of reduction. $M_2S$ oxidation may require more coke for reduction and therefore may also result in more unreacted coke to be filtered. This is the subject of a discussion in Section 6, Paragraph f.

4) Both the fly ash and coke filters provide a dry cake discharge.

5) Soluble lithium salts react in the aqueous phase with soluble carbonate salts to form insoluble $Li_2CO_3$ and is recovered to the extent of 88 percent. $Li_2CO_3$ delivered cost is 42 cents per pound.

The result of this evaluation for a high temperature electrostatic precipitator operating at an efficiency of 99.5 percent, is summarized in Table 6-8. At other efficiencies, only the $Li_2CO_3$ associated with fly ash will be affected since the KCl and coke are constant at the different efficiencies.

The table lists the equivalent capital investment required to recover the lithium carbonate contained in the inerts. An engineering flow diagram of the tentative aqueous process was prepared and estimates indicate that the installed cost for such a process to recover the lithium carbonate from all sources would be less than $500,000. The justifiable capital cost of the recovered lithium carbonate in the fly ash only, is substantially greater than the $500,000 installed cost of the process thereby justifying its inclusion in the overall process scheme.

Table 6-8. Value of $Li_2CO_3$ Recovered in an Aqueous Recovery Process

| | Electrostatic Precipitator Efficiency |
|---|---|
| | 99.5% |
| Filter Cake Inerts | |
| FlyAsh, #/Hr. | 225 |
| KCl, #/Hr. | 403 |
| Coke, #/Hr. | 800 |
| $Li_2CO_3$ Recovery, #/Yr, From | |
| FlyAsh, (0.492#/#Flyash) | 679,000 |
| KCl, (0.492#/#KCl) | 1,216,000 |
| Coke, (0.308#/#Coke) | 1,511,000 |
| Total | 3,406,000 |
| Annual Value for $Li_2CO_3$ Recovered From | |
| FlyAsh | $285,000 |
| KCl | 511,000 |
| Coke | 635,000 |
| Total Annual Value of Recovered $Li_2CO_3$ | $1,431,000 |
| Justifiable Capital Investment Required to Recover $Li_2CO_3$ From | |
| FlyAsh | $2,035,000 |
| KCl | 3,650,000 |
| Coke | 4,535,000 |
| Total | $10,220,000 |

The engineering flow diagram for the lithium carbonate recovery process is shown on Drawing No. PS-218-0004 and is the basis for the capital costs used in the process evaluation.

The economics for inclusion of a lithium carbonate recovery process should be reevaluated if the associated melt losses can be reduced at the fly ash filter.

### g. Copper Smelter

The study of the removal of $SO_2$ from copper smelter gases has been limited to those gases emanating from reverberatory furnace operations only. Roaster gases contain high $SO_2$ concentrations and can be utilized in conventional acid plants as can the converter gases. The possibility of converter gases being used as feed to the Molten Carbonate Process is discussed in Section 5, Paragraph j.

The treatment of reverberatory furnace gases for removal of particulate matter varies considerably from smelter to smelter. The gases generally flow from the reverberatory furnace through a waste heat boiler exiting at temperatures ranging from 600°F to 700°F. At this point some smelters cool the gases to about 350°F by dilution with ambient air so that a bag house can be used to remove the particulate matter. Current practice in new plants is to employ electrostatic precipitators operating at the 600°F-700°F temperature level for removal of particulate matter.

For this study, a hypothetical reverberatory furnace has been selected that will produce 200 tons per day of copper. It has been assumed that the gases from the furnace and waste heat boiler contain 2 percent $SO_2$ by volume with the equivalent of 50 tons per day of contained sulfur.

Several cases have been investigated:

Case (a): Integration of the Molten Carbonate Process into the hypothetical smelter with existing bag house filters by reheating the 350°F gas to 850°F by indirect exchange of heat with absorber off-gas followed by direct combustion of fuel into the gas stream.

Case (b): The smelter has an existing 600°F electrostatic precipitator and the off-gases must be reheated as in Case (a).

Case (c): The gases from the waste heat boiler exit at 800-850°F rather than 600-700°F and are passed through a new high temperature electrostatic precipitator.

The results of the investigation are listed in Table 6-9.

The operating costs have been based on the following:

1. 7920 hours per year of operation(90% Plant Factor).

2. Fuel costs for reheat in Case (a) and Case (b).

3. Penalty at the value of equivalent fuel for Case (c) due to rejecting heat at the Waste Heat Boiler at 850°F rather than 700°F. No benefit has been applied to the possible use of the 850°F absorber off-gas as a source of heat in a recuperator.

4. Power costs for cases (a) and (b) include increased pressure drop for the reheat system and absorber.

5. Power cost for case (c) includes the increased pressure drop for the absorber.

6. The power cost attributable to the bag house pressure drop in case (a) is approximately the same as the electrostatic precipitator power costs in cases (b) and (c) and therefore these costs were not considered.

The capital cost does not include any salvage or scrap value for discarded equipment. Nor does it include possible new fans to overcome the increased pressure drop in cases (a) and (b).

The evaluation shows that in the hypothetical smelter with an existing bag house it is less expensive to abandon the bag house and install a new electrostatic precipitator operating at 800-850°F. This is not true if the smelter is equipped with an electrostatic precipitator operating at 600°F; it is then less expensive to install the reheat system.

The capital and operating costs for the application of the Molten Carbonate Process for removal of $SO_2$ from reverberatory furnace gases has been based on a smelter equipped with an existing 600°F electrostatic precipitator.

The method that is to be employed to provide the 800°F-850°F gas to the absorber in the Molten Carbonate Process must be re-examined when an actual existing smelter is selected.

If a new copper smelter were to be considered, it is clear that an electrostatic precipitator operating at 800-850°F and a suitable resistivity would result in lowest cost.

Table 6-9. Integration Into Existing Typical Copper Smelter Reverberatory Furnace Circuit

| | Case (a) | Case (b) | Case (c) |
|---|---|---|---|
| Type | Reheat (Off-Gases from Bag House @ 350 °F) | Reheat (Off-Gases from Electrostatic Precipitator @ 600 °F) | No Reheat (Off-Gases at 850 °F through new electrostatic precipitator) |
| Capital Costs | | | |
| Reheat System | $240,000 | $176,000 | Not Required |
| Electrostatic Precipitator | Not Required | Existing, Assumed Amortized | $300,000 |
| Absorber Cost & Size | 100,000(14'-6"Ø) | 60,000(9'-6"Ø) | 60,000(9'-6"Ø) |
| TOTAL | $340,000 | $236,000 | $360,000 |
| Annual Costs | | | |
| Capital Charges (14% of capital costs) | 47,000 | 33,000 | 50,400 |
| Fuel(40¢/million BTU) | 25,300 | 13,100 | 23,300<br>(Penalty for rejecting waste heat at higher temperatures) |
| Power (6mills/KWH) | 14,400 | 8,900 | 2,200 |
| TOTAL | 87,300 | 55,000 | 76,900 |

## 7. EQUIPMENT - BASE CASE PLANT

### a. List of Equipment

### 1) $SO_x$ Removal and Coke Handling Facilities

| Tag Number | Description |
|---|---|
| B-1A, 1B, 1C, 1D | Combustion Air Blower |
| B-2 | Filter Displacement Blower |
| C-1 | Crusher |
| E-1A,1B | Reducer Product Cooler |
| E-2A,2B,2C,2D | Air-Oxidation Zone Exchanger |
| E-3 | (Not Used) |
| E-4 | Regenerator Bottoms Cooler |
| E-5 | Regenerator Intermediate Cooler |
| F-1A,1B | Fly Ash Filter |
| F-2A,2B | Coke Filter |
| G-1 | Transfer Conveyor with Vibrating Feeder |
| G-2 | Bucket Elevator |
| G-3 | Coke Bucket Elevator |
| G-4 | Reversing Conveyor |
| G-5 | Coke Belt Conveyor with Movable Tripper |
| G-5A | Elevating Belt Conveyor |
| G-6,7,8 | Dust Collectors |

| | |
|---|---|
| G-9 | Carbonate Bucket Elevator |
| G-10 | Eutectic Conveyor |
| G-11 | $M_2CO_3$ Silo Feed Conveyor with Tripper |
| P-1A,1A(S),1B,1B(S)<br>1C,1 (S),1D,1D(S) | Absorber Pump |
| P-2A,2A(S),2B,2B(S) | Reducer Pump |
| P-3,P-3(S) | Regenerator Bottoms Pump |
| P-4,P-4(S) | Regenerator Intermediate Pump |
| P-5 | Makeup Pump |
| S-1 | Screen |
| T-1,T-2 | Coke Silo |
| T-3 | $Na_2CO_3$ Silo w/Dust Collector |
| T-4 | $K_2CO_3$ Silo w/Dust Collector |
| T-5 | $Li_2CO_3$ Silo w/Dust Collector |
| V-1A,1B,1C,1D | Absorber |
| V-2A,2B,2C,2D | Absorber Pump Tank |
| V-3A,3B,3C,3D | Reducer |
| V-4A,4B | Reducer Quench Tank |
| V-5 | Regenerator |
| V-6 | Regenerator Bottoms Pump Tank |
| V-7 | Regenerator Intermediate Pump Tank |
| V-8A,8B,8C,8D | Coke Bin |

| | |
|---|---|
| V-9 | $M_2CO_3$ Melt Tank |
| W-1A,1B,1C,1D | Coke Weigh Feeder |
| X-1A,1B,1C,1D | Electrostatic Precipitator |
| X-2 | Instrument Air Compressor |
| X-3 | Instrument Air Dryer |

### 2) $Li_2CO_3$ Recovery

| Tag Number | Description |
|---|---|
| A-101 | Agitator for Dissolving Sump, T-110 |
| A-102 | Agitator for Fly Ash & Coke Slurry Tank, T-101 |
| A-103 | Agitator for $LiHCO_3$ Reactor, V-101 |
| A-104 | Agitator for Fly Ash Filter Cake Receiver, T-102 |
| A-105 | Agitator for $LiHCO_3$ Reactor Product Surge, T-103 |
| A-106 | Agitator for $Li_2CO_3$ Reactor, V-102 |
| A-107 | Agitator for $Li_2CO_3$ Reactor Product Surge, T-104 |
| B-101 | Exhaust Fan |
| B-102 | Hot Air Blower |
| D-101 | $Li_2CO_3$ Dryer |
| F-101 | $Li_2CO_3$ Fly Ash Filter incl. Vacuum Pump |
| F-102 | Fly Ash Filter incl. Vacuum Pump |

| | |
|---|---|
| F-103 | $Li_2CO_3$ Filter incl. Vacuum Pump |
| G-101 | Redler Conveyor |
| P-101,101(S) | Dissolving Sump Pump |
| P-102 | Soluble Salt Receiver Pump |
| P-103,103(S) | Fly Ash Coke Slurry Tank Pump |
| P-104,104(S) | $LiHCO_3$ Reactor Product Surge Pump |
| P-105 | $Li_2CO_3$ Reactor Transfer Pump |
| P-106 | $Li_2CO_3$ Reactor Product Surge Tank Pump |
| P-107 | $Li_2CO_3$ Filtrate Receiver Pump |
| P-108 | $Li_2CO_3$ Fly Ash Filter Cake Receiver Pump |
| P-109 | $LiHCO_3$ Filtrate Receiver Pump |
| T-101 | Fly Ash Coke Slurry Tank |
| T-102 | $Li_2CO_3$ Fly Ash Filter Cake Receiver |
| T-103 | $LiHCO_3$ Reactor Product Surge |
| T-104 | $Li_2CO_3$ Reactor Product Surge |
| T-105 | Surge Drum |
| T-106 | (Not Used) |
| T-107 | Soluble Salt Receiver |
| T-108 | $LiHCO_3$ Filtrate Receiver |
| T-109 | $Li_2CO_3$ Filtrate Receiver |
| V-101 | $LiHCO_3$ Reactor |

| | |
|---|---|
| V-102 | $Li_2CO_3$ Reactor |
| X-101 | Inert Gas Generator including Compressor |

b. Specifications

The specifications for major equipment required in the $SO_x$ removal process are attached to this section of the report. The specifications are of a functional nature rather than a detailed nature.

## Functional Specification for Combustion Air Blower B-1A,B,C,D

Number of Units - 4

Gas Handled - Atmospheric air

Quantity Handled - 6000 SCFM

Design Temperature - 150

Operating Temperature - Ambient (range 20 °F - 90 °F)

Suction Pressure - Atmospheric

Pressure Difference Across Blower - 7 psi

## Functional Specification for Filter Displacement Blower B-2

Number of Units - 1

Composition of Gas Handled - $N_2$ - 75% by volume
$CO_2$- 13%
$H_2O$- 8%
$O_2$ - 4%
$SO_2$- Trace

Quantity Handled - 150 ACFM

Design Temperature - 1000 °F

Operating Temperature - 850 °F

Suction Pressure - 10" W.G. negative

Pressure Differential Across Blower - 3 psi

An alternative design would call for air heated by melt or electric heaters.

Exchangers E-1A & 1B, E-4 & E-5 specified hereafter are to be the air-cooled type with external air recirculation to minimize freezing of the process liquid, and intake air heating coils for start-up operation.

Req'd: 2 in parallel

GENERAL ENGINEERING DIVISION
FORM 66-57 6-54 R-1

# HEAT EXCHANGER SPECIFICATION

## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING.
ITEMS MARKED * MAY BE OMITTED UNTIL SELECTION OF VENDOR.

SHEET NO. 1 REV.
DATE 10-27-70
BY SD CHK'D

ITEM NO. E-1A&B SERVICE Reducer Product Cooler JOB NO. PS-218
DUTY $23.7 \times 10^6$ BTU/HR. EXCHANGER TYPE: HORIZ., VERT. Air-Cooled "Fin-Fan" Type
VENDOR MFRS. IDENT. NO.

| | | | | |
|---|---|---|---|---|
| FLUID | Air | | Molten Carbonate | |
| TOTAL FLOW ... LBS/HR | | | 530,000 | |
| SHELL OR TUBE SIDE | Shell | | Tube | |
| | INLET | OUTLET | INLET | OUTLET |
| LIQUID (EXCLUDING WATER) ... LBS/HR | | | | |
| DENSITY ... LBS/CU FT | @ °F | @ °F | @ °F | @ °F |
| THERMAL COND. .. BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | @ °F | @ °F | 0.45 @ aver °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| VAPOR (EXCLUDING STEAM) ... LBS/HR | | | | |
| MOLECULAR WEIGHT | | | 107.7 | |
| THERMAL COND. .. BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | 0.25 @ aver °F | @ °F | @ °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| STEAM ... LBS/HR | | | | |
| WATER ... LBS/HR | | | | |
| ADDITIONAL DATA ON SHEET NO. | | | | |
| OPERATING TEMPERATURES ... °F | 70° | - | 350 | 850 |
| PRESSURES ... PSIG | | | | |
| VELOCITIES ... FT/SEC | | | | |
| PRESSURE DROP (NOTE A) ... PSI | ALLOW. | CALC. | ALLOW. 40 PSI | CALC. |
| DESIGN TEMPERATURES ... °F | | | | |
| PRESSURE ... PSIG | MIN. ACTUAL | TEST | MIN. ACTUAL | TEST |
| FOUL. RESIST. ... SQ FT X HR X °F/BTU | MIN. | CALC. | MIN. | CALC. |
| MIN. CORROSION ALLOWANCE ... IN. | | | | |
| NUMBER OF PASSES PER SHELL | | | | |
| FLOW ARRANGEMENT | PAR. BANKS OF | EXCH. IN SERIES | PAR. BANKS OF | EXCH. IN SERIES |

| | | | | | |
|---|---|---|---|---|---|
| TOT. AREA (NOTE B) SQ FT | | SHELL (OR SECTS) TOTAL NO. | | CROSS BAFFLES, TYPE.. | |
| LMTD | | I.D. | IN. | NUMBER X SPACING | X IN. |
| CORRECTED MTD | | TUBES, NO. PER SHELL | | SEGMENT CUT | |
| TRANSFER RATE, CLEAN | | O.D. X LENGTH | IN. X IN. | TUBE HOLE DIAM. | • IN. |
| SERVICE | | GAUGE, BWG. | AVE., MIN. WALL | RADIAL CLEARANCE | • IN. |
| | | PITCH | IN. △ ☐ ◇ | LONG BAFFLE, TYPE | |
| CODE REQUIREMENTS | API-ASME: TEMA | TUBE LIMIT DIAM. OR WIDTH | IN. | LENGTH | • IN. |
| REMOVABLE TUBE BUNDLE | YES NO | WEIGHTS EACH BUNDLE | LBS | DIST. ABOVE SHELL | IN. |
| FLOATING HEAD | CLAMP-RING: PULL THRU | BUNDLE & SHELL | LBS | REBOILER WEIR HEIGHT | IN. |
| IMPINGEMENT BAFFLE | YES NO | FULL OF WATER | LBS | SHELL AFTER WEIR | FT. |

MATERIALS (MARK STRESS RELIEVED – S.R., RADIOGRAPHED – X.R.)

| | | THICK., IN. | GASKETS |
|---|---|---|---|
| TUBES | Type 347SS | | |
| TUBE SHEETS | | • | |
| BAFFLES | | • | |
| TUBE SUPPORTS | | • | |
| TIE RODS & SPACERS | | • | |
| LONG BAFFLE | | • | |
| SHELL | | • | |
| SHELL COVER | | • | |
| CHANNEL | | • | |
| CHANNEL COVER | | • | |
| FLOATING HEAD COVER | | • | |

NOZZLES (NOTE C)

| | TUBE SIDE | | SHELL SIDE | | |
|---|---|---|---|---|---|
| | SIZE | RATING | LIQ. | VAP. | RATING |
| INLET | | | | | |
| OUTLET | | | | | |
| DRAIN | | | | | |
| VENT | | | | | |
| RELIEF | | | | | |

REMARKS: * Melt Composition, Mol% Approx.: $M_2SO_4$ 1.3: $M_2CO_3$ 62.9:KCl 3.8
Freezing Point 750°F
Quantities Listed are for One Cooler.

NOTE A: FOR CONDENSERS AND THERMOSYPHON REBOILERS PRESSURE DROP STATED SHALL INCLUDE STATIC HEAD BETWEEN CENTERLINES OF INLET AND OUTLET FLANGES.
NOTE B: OUTSIDE TUBE AREA EXCLUDING AREA IN TUBE SHEETS.
NOTE C: RATE PER ASA B 16E – 1939 OR ASA B 16E9 – 1949.

4 Req'd in parallel

**GENERAL ENGINEERING DIVISION**
FORM 66-57 6-54 R-1

# HEAT EXCHANGER SPECIFICATION

## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING.
ITEMS MARKED * MAY BE OMITTED UNTIL SELECTION OF VENDOR.

SHEET NO. 2 REV.
DATE 10-27-70
BY SD CHK'D
JOB NO. PS-218

ITEM NO. E-2A, B, C, D SERVICE Air-Oxidation Zone Exchanger
DUTY $4.5\ 10^6$ BTU/HR. EXCHANGER TYPE: HORIZ., VERT. Vertical
VENDOR MFRS. IDENT. NO.

| | | | | |
|---|---|---|---|---|
| FLUID | Air | | Gas* | |
| TOTAL FLOW ... LBS/HR | 23,850 | | 25,500 | |
| SHELL OR TUBE SIDE | Shell | | Tube | |
| | INLET | OUTLET | INLET | OUTLET |
| LIQUID (EXCLUDING WATER) ... LBS/HR | | | | |
| DENSITY ... LBS/CU FT | @ °F | @ °F | @ °F | @ °F |
| THERMAL COND. ... BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | @ °F | @ °F | @ °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| VAPOR (EXCLUDING STEAM) ... LBS/HR | 23,350 | | | |
| MOLECULAR WEIGHT | 29 | | 30.3 | |
| THERMAL COND. ... BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | 0.242 @ Avg. °F | @ °F | 0.271 @ Avg. °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| STEAM ... LBS/HR | 500 | | 325 | |
| WATER ... LBS/HR | | | | |
| ADDITIONAL DATA ON SHEET NO. | | | | |
| OPERATING TEMPERATURES ... °F | 153 | 915° | 1500 | 850° |
| PRESSURES ... PSIG | 7 | | | |
| VELOCITIES ... FT/SEC | | | | |
| PRESSURE DROP (NOTE A) ... PSI | ALLOW. 6"W.G. | CALC. | ALLOW. 3PSI | CALC. |
| DESIGN TEMPERATURE ... °F | | | | |
| PRESSURE ... PSIG | MIN. | ACTUAL 10 TEST | MIN. | ACTUAL TEST |
| FOUL. RESIST. ... SQ FT X HR X °F/BTU | MIN. | CALC. | MIN. | CALC. |
| MIN. CORROSION ALLOWANCE ... IN. | | | | |
| NUMBER OF PASSES PER SHELL | | | | |
| FLOW ARRANGEMENT | PAR. BANKS OF | EXCH. IN SERIES | PAR. BANKS OF | EXCH. IN SERIES |

| | | | | | |
|---|---|---|---|---|---|
| TOT. AREA (NOTE B) SQ FT | | SHELL (OR SECTS) TOTAL NO. | | CROSS BAFFLES, TYPE | |
| LMTD | | I.D. | IN. | NUMBER X SPACING | X IN. |
| CORRECTED MTD | | TUBES, NO. PER SHELL | | SEGMENT CUT | |
| TRANSFER RATE, CLEAN | | O.D. X LENGTH | IN. X IN. | TUBE HOLE DIAM. | * IN. |
| SERVICE | | GAUGE, BWG | AVE., MIN. WALL | RADIAL CLEARANCE | * IN. |
| | | PITCH | IN. △ □ ◇ | LONG BAFFLE, TYPE | |
| CODE REQUIREMENTS | API-ASME; TEMA | TUBE LIMIT DIAM. OR WIDTH | IN. | LENGTH | * IN. |
| REMOVABLE TUBE BUNDLE | YES NO | WEIGHTS EACH BUNDLE | LBS | DIST. ABOVE SHELL | IN. |
| FLOATING HEAD | CLAMP-RING; PULL THRU | BUNDLE & SHELL | LBS | REBOILER WEIR HEIGHT | IN. |
| IMPINGEMENT BAFFLE | YES NO | FULL OF WATER | LBS | SHELL AFTER WEIR | FT. |

MATERIALS (MARK STRESS RELIEVED – S.R., RADIOGRAPHED – X.R.)

| | | THICK., IN. |
|---|---|---|
| TUBES | Type 347SS | |
| TUBE SHEETS | | * |
| BAFFLES | | * |
| TUBE SUPPORTS | | * |
| TIE RODS & SPACERS | | * |
| LONG BAFFLE | | * |
| SHELL | | * |
| SHELL COVER | | * |
| CHANNEL | | * |
| CHANNEL COVER | | * |
| FLOATING HEAD COVER | | * |

NOZZLES (NOTE C)

| | TUBE SIDE | | SHELL SIDE | | |
|---|---|---|---|---|---|
| | SIZE | RATING | LIQ. | VAP. | RATING |
| INLET | | | | | |
| OUTLET | | | | | |
| DRAIN | | | | | |
| VENT | | | | | |
| RELIEF | | | | | |

GASKETS

REMARKS: * Gas Analysis (Mol%) $CO_2$-16.8; $N_2$-80.5; $H_2O$-2.3; Hydrocarb-0.4

Quantities Listed Are For One Cooler.

NOTE A: FOR CONDENSERS AND THERMOSYPHON REBOILERS PRESSURE DROP STATED SHALL INCLUDE STATIC HEAD BETWEEN CENTERLINES OF INLET AND OUTLET FLANGES.
NOTE B: OUTSIDE TUBE AREA EXCLUDING AREA IN TUBE SHEETS.
NOTE C: RATE PER ASA B 16E – 1939 OR ASA B 16E5 – 1943.

One Req'd

GENERAL ENGINEERING DIVISION
FORM 66-57 6-54 R-1

# HEAT EXCHANGER SPECIFICATION

## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING.
ITEMS MARKED * MAY BE OMITTED UNTIL SELECTION OF VENDOR.

SHEET NO. 3 REV.
DATE 10-27-70
BY SD CHK'D
JOB NO. PS-218

ITEM NO. E-4 SERVICE Regenerator Bottoms Cooler
DUTY $10 \times 10^6$ BTU/HR. EXCHANGER TYPE: HORIZ., VERT. Air-Cooled "Fin-Fan" Unit
VENDOR MFRS. IDENT. NO.

| | | | | |
|---|---|---|---|---|
| FLUID | Air | | Molten Carbonates | |
| TOTAL FLOW ........ LBS/HR | | | 300,000 | |
| SHELL OR TUBE SIDE | Shell | | Tube | |
| | INLET | OUTLET | INLET | OUTLET |
| LIQUID (EXCLUDING WATER) ...... LBS/HR | | | | |
| DENSITY ........ LBS/CU FT | ● °F | ● °F | ● °F | ● °F |
| THERMAL COND... BTU/HR X SQ FT X °F/FT | ● °F | ● °F | ● °F | ● °F |
| SPECIFIC HEAT ........ BTU/LB X °F | ● °F | ● °F | 0.45 ● Avg. °F | ● °F |
| VISCOSITY ........ CENTIPOISES | ● °F | ● °F | ● °F | ● °F |
| | ● °F | ● °F | ● °F | ● °F |
| VAPOR (EXCLUDING STEAM) ....... LBS/HR | | | | |
| MOLECULAR WEIGHT | | | 100 Approx. | |
| THERMAL COND... BTU/HR X SQ FT X °F/FT | ● °F | ● °F | ● °F | ● °F |
| SPECIFIC HEAT ........ BTU/LB X °F | ● °F | ● °F | ● °F | ● °F |
| VISCOSITY ........ CENTIPOISES | ● °F | ● °F | ● °F | ● °F |
| | ● °F | ● °F | ● °F | ● °F |
| STEAM ........ LBS/HR | | | | |
| WATER ........ LBS/HR | | | | |
| ADDITIONAL DATA ON SHEET NO. ...... | | | | |
| OPERATING TEMPERATURES ........ °F | 70° | | 925° | 850° |
| PRESSURES ........ PSIG | | | | |
| VELOCITIES ........ FT/SEC | | | | |
| PRESSURE DROP (NOTE A) ........ PSI | ALLOW. | CALC. | ALLOW. 25 PSI | CALC. |
| DESIGN TEMPERATURE ........ °F | | | | |
| PRESSURE ........ PSIG | MIN. ACTUAL | TEST | MIN. ACTUAL | TEST |
| FOUL. RESIST. ...... SQ FT X HR X °F/BTU | MIN. | CALC. | MIN. | CALC. |
| MIN. CORROSION ALLOWANCE ........ IN. | | | | |
| NUMBER OF PASSES PER SHELL ...... | | | | |
| FLOW ARRANGEMENT ........ | PAR. BANKS OF | EXCH. IN SERIES | PAR. BANKS OF | EXCH. IN SERIES |

| | | | | | |
|---|---|---|---|---|---|
| TOT. AREA (NOTE B) SQ FT | | SHELL (OR SECTS) TOTAL NO. | | CROSS BAFFLES, TYPE.. | |
| LMTD ........ | | I.D. ........ | IN. | NUMBER X SPACING. | X IN. |
| CORRECTED MTD ........ | | TUBES, NO. PER SHELL.... | | SEGMENT CUT....... | |
| TRANSFER RATE, CLEAN | | O.D. X LENGTH ........ | IN. X IN. | TUBE HOLE DIAM.... | ● IN. |
| SERVICE | | GAUGE, BWG. ........ | AVE., MIN. WALL | RADIAL CLEARANCE.. | ● IN. |
| | | PITCH ........ | IN. △ ☐ ◇ | LONG BAFFLE, TYPE... | |
| CODE REQUIREMENTS.... | API-ASME: TEMA | TUBE LIMIT DIAM. OR WIDTH | IN. | LENGTH ........ | ● IN. |
| REMOVABLE TUBE BUNDLE | YES NO | WEIGHTS EACH BUNDLE... | LBS | DIST. ABOVE SHELL.. | IN. |
| FLOATING HEAD ........ | CLAMP-RING; PULL THRU | BUNDLE & SHELL....... | LBS | REBOILER WEIR HEIGHT | IN. |
| IMPINGEMENT BAFFLE ... | YES NO | FULL OF WATER....... | LBS | SHELL AFTER WEIR.. | FT. |

MATERIALS (MARK STRESS RELIEVED — S.R., RADIOGRAPHED — X.R.)

| | | |
|---|---|---|
| TUBES ........ | Type 347SS | THICK., IN. |
| TUBE SHEETS........ | | ● |
| BAFFLES ........ | | ● |
| TUBE SUPPORTS...... | | ● |
| TIE RODS & SPACERS.. | | ● |
| LONG BAFFLE........ | | ● |
| SHELL ........ | | ● |
| SHELL COVER ........ | | ● |
| CHANNEL ........ | | ● |
| CHANNEL COVER ..... | | ● |
| FLOATING HEAD COVER | | ● |

NOZZLES (NOTE C)

| | TUBE SIDE | | SHELL SIDE | | |
|---|---|---|---|---|---|
| | SIZE | RATING | LIQ. | VAP. | RATING |
| INLET ........ | | | | | |
| OUTLET ........ | | | | | |
| DRAIN ........ | | | | | |
| VENT ........ | | | | | |
| RELIEF ........ | | | | | |

GASKETS

REMARKS: Melt Composition, Mol% Approx: $M_2S$ 1.6%; $M_2SO_4$ 1.3; $M_2CO_3$ 93.3; KCl 3.8; Freezing Point 750°F

NOTE A: FOR CONDENSERS AND THERMOSYPHON REBOILERS PRESSURE DROP STATED SHALL INCLUDE STATIC HEAD BETWEEN CENTERLINES OF INLET AND OUTLET FLANGES.
NOTE B: OUTSIDE TUBE AREA EXCLUDING AREA IN TUBE SHEETS.
NOTE C: RATE PER ASA B 16E — 1939 OR ASA B 16E5 — 1943.

One Req'd

GENERAL ENGINEERING DIVISION
FORM 66-57 6-54 R-1

# HEAT EXCHANGER SPECIFICATION

SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING.
ITEMS MARKED * MAY BE OMITTED UNTIL SELECTION OF VENDOR.

SHEET NO. 4 REV.
DATE 10-28-70
BY SD CHK'D
JOB NO. PS-218

ITEM NO. E-5 SERVICE Regenerator Intermediate Cooler
DUTY 15x10⁶ BTU/HR. EXCHANGER TYPE: HORIZ., VERT. Air-Cooled "Fin-Fan" Unit
VENDOR MFRS. IDENT. NO.

| | | | | |
|---|---|---|---|---|
| FLUID | Air | | Molten Carbonates | |
| TOTAL FLOW ... LBS/HR | | | 334,000 | |
| SHELL OR TUBE SIDE | INLET Shell | OUTLET | INLET Tube | OUTLET |
| LIQUID (EXCLUDING WATER) ... LBS/HR | | | | |
| DENSITY ... LBS/CU FT | @ °F | @ °F | @ °F | @ °F |
| THERMAL COND. ... BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | @ °F | @ °F | 0.45 @ Avg. °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| VAPOR (EXCLUDING STEAM) ... LBS/HR | | | | |
| MOLECULAR WEIGHT | | | 100Approx. | |
| THERMAL COND. ... BTU/HR X SQ FT X °F/FT | @ °F | @ °F | @ °F | @ °F |
| SPECIFIC HEAT ... BTU/LB X °F | @ °F | @ °F | @ °F | @ °F |
| VISCOSITY ... CENTIPOISES | @ °F | @ °F | @ °F | @ °F |
| | @ °F | @ °F | @ °F | @ °F |
| STEAM ... LBS/HR | | | | |
| WATER ... LBS/HR | | | | |
| ADDITIONAL DATA ON SHEET NO. | | | | |
| OPERATING TEMPERATURES ... °F | 70° | | 950° | 850° |
| PRESSURES ... PSIG | | | | |
| VELOCITIES ... FT/SEC | | | | |
| PRESSURE DROP (NOTE A) ... PSI | ALLOW. | CALC. | ALLOW. 25 PSI | CALC. |
| DESIGN TEMPERATURE ... °F | | | | |
| PRESSURE ... PSIG | MIN. ACTUAL | TEST | MIN. ACTUAL | TEST |
| FOUL. RESIST. ... SQ FT X HR X °F/BTU | MIN. | CALC. | MIN. | CALC. |
| MIN. CORROSION ALLOWANCE ... IN. | | | | |
| NUMBER OF PASSES PER SHELL | | | | |
| FLOW ARRANGEMENT | PAR. BANKS OF | EXCH. IN SERIES | PAR. BANKS OF | EXCH. IN SERIES |

| | | | | | |
|---|---|---|---|---|---|
| TOT. AREA (NOTE B) SQ FT | | SHELL (OR SECTS) TOTAL NO. | | CROSS BAFFLES, TYPE | |
| LMTD | | I.D. | IN. | NUMBER X SPACING | X IN. |
| CORRECTED MTD | | TUBES, NO. PER SHELL | | SEGMENT CUT | |
| TRANSFER RATE, CLEAN | | O.D. X LENGTH | IN. X IN. | TUBE HOLE DIAM. | * IN. |
| SERVICE | | GAUGE, BWG. | AVE., MIN. WALL | RADIAL CLEARANCE | * IN. |
| | | PITCH | IN. △ □ ◇ | LONG BAFFLE, TYPE | |
| CODE REQUIREMENTS | API-ASME: TEMA | TUBE LIMIT DIAM. OR WIDTH | IN. | LENGTH | * IN. |
| REMOVABLE TUBE BUNDLE | YES NO | WEIGHTS EACH BUNDLE | LBS | DIST. ABOVE SHELL | IN. |
| FLOATING HEAD | CLAMP-RING; PULL THRU | BUNDLE & SHELL | LBS | REBOILER WEIR HEIGHT | IN. |
| IMPINGEMENT BAFFLE | YES NO | FULL OF WATER | LBS | SHELL AFTER WEIR | FT. |

MATERIALS (MARK STRESS RELIEVED – S.R., RADIOGRAPHED – X.R.)

| | | THICK., IN. |
|---|---|---|
| TUBES | Type 347SS | |
| TUBE SHEETS | | * |
| BAFFLES | | * |
| TUBE SUPPORTS | | * |
| TIE RODS & SPACERS | | * |
| LONG BAFFLE | | * |
| SHELL | | * |
| SHELL COVER | | * |
| CHANNEL | | * |
| CHANNEL COVER | | * |
| FLOATING HEAD COVER | | * |

NOZZLES (NOTE C)

| | TUBE SIDE SIZE | TUBE SIDE RATING | SHELL SIDE LIQ. | SHELL SIDE VAP. | SHELL SIDE RATING |
|---|---|---|---|---|---|
| INLET | | | | | |
| OUTLET | | | | | |
| DRAIN | | | | | |
| VENT | | | | | |
| RELIEF | | | | | |

GASKETS

REMARKS: Melt Composition, Mol% Approx.: $M_2S$ 13.8; $M_2SO_4$ 1.3; $M_2CO_3$ 81.1; KCl 3.8 Freezing Point 750°F

NOTE A: FOR CONDENSERS AND THERMOSYPHON REBOILERS PRESSURE DROP STATED SHALL INCLUDE STATIC HEAD BETWEEN CENTERLINES OF INLET AND OUTLET FLANGES.
NOTE B: OUTSIDE TUBE AREA EXCLUDING AREA IN TUBE SHEETS.
NOTE C: RATE PER ASA B 16F – 1939 OR ASA B 16E3 – 1943.

## Functional Specification for

## Fly Ash Filter, Tag No. F-1A & F-1B

Types of Units - Pressure leaf
2 units in parallel,
Cyclic operation - one unit in operation while other unit is being drained and "dry" cake is discharged.

Material of construction - Type 347 stainless steel

Design Pressure - 150 psig

Design Temperature - 1000 °F

Type of Cake Discharge - Fixed blades against rotary leaves

Filtration Area - 1000 sq. ft. per unit

Cycle Time - 45 minutes

Cake Thickness at End of Cycle - 1/8"

Cake Washing - None

Liquid Flow - 180,000 lb/hr.

Liquid Composition - Mixture of molten salts-sodium, potassium and lithium carbonates, sulphates, sulphites and sulphides

Liquid Specific Gravity - 2.0

Liquid Viscosity - 12 cp

Solids Flow - 630 lb/hr. (400 lb/hr of KCl, 230 lb/hr. of fly ash) plus trace of coke.

Media Opening - 25 micron

Percent Solids in "Dry Cake" - 35%

## Functional Specification for

## Coke Filter, Tag No. F-2A & F-2B

Type of Units - Pressure leaf
2 units in parallel
Cyclic operation - one unit in operation while other unit is being drained and "dry" coke is discharged.

Materials of Construction - Type 347 stainless steel

Design Pressure - 150 psg

Design Temperature - 1000 °F

Type of Cake Discharge - Fixed blade against rotary leaves

Filtration Area - 1000 sq. ft. per unit

Cycle Time - 45 minutes

Cake Thickness End of Cycle - 1/8"

Cake Washing - None

Liquid Flow - 180,000 lb/hr.

Liquid Composition - Mixture of molten salts sodium, potassium and lithium carbonates, sulphates, sulphites, and sulphides

Liquid Specific Gravity - 2.0

Liquid Viscosity - 12 cp

Solids Flow - 880 lb/hr. of coke plus traces of KCL and fly ash

Medium Opening - 25 microns

Percent Solids in "Dry Cake" - 50%

P-1B, 1B(S)
P-1C, 1C(S)
P-1D, 1D(S)
ITEM NO.

# CENTRIFUGAL PUMP SPECIFICATION
## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING

SHEET NO. 1 REV.
DATE 11-16-70
BY SF CHK'D.
JOB NO. PS-218
MFR'S TYPE NO.

SERVICE Absorber Pumps
NO. REQ'D. 8 MOTOR DRIVEN, AND DRIVEN. VENDOR

LIQUID PUMPED Molten Carbonate Salt
CORROSION OR EROSION FACTORS

### OPERATING CONDITIONS

PUMPING TEMPERATURE 850-900 °F.

|  |  |
|---|---|
| FLOW @ P.T. 720 GPM | DIFFERENTIAL 112 PSI FT. (1) |
| SPEC. GR. @ P.T. 2.0 | DISCHARGE PSIG |
| VISCOS. @ P.T. 12. C.P. | SUCTION PSIG |
|  | BAROMETRIC PSIA |
|  | NPSH AVAILABLE FT. |
|  | NPSH REQUIRED FT. |

### MATERIALS

| MATERIALS | BRINELL HARDNESS OF WEAR'G PARTS |
|---|---|
| CASE: INNER |  |
| OUTER All Wetted Parts |  |
| WEAR RINGS to be S.S. Type 347 |  |
| STUDS AND NUTS |  |
| GASKETS |  |
| IMPELLER |  |
| WEAR RINGS |  |
| DIFFUSERS |  |
| INTERSTG. PIECE |  |
| INTERSTG. BUSHING |  |
| SHAFT |  |
| STUFF. BOX SHAFT SLEEVES |  |
| INTERSTG. SHAFT SLEEVE |  |
| STUFFING BOX |  |
| PACKING GLAND |  |
| GLAND STUDS |  |
| LANTERN RING |  |
| THROAT BUSHING |  |
| BALANCING DRUM |  |
| PRESS. BAL. SLEEVE |  |
| BEARING HOUSING |  |

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PUMP TYPE:* (HORIZ: VERT. SUBMERG; VERT. SUCT.; REGEN. TURB.)
PUMP SIZE ; NO. OF STAGES ; SPEED RPM
HYDRAULIC H.P. EFFICIENCY @ RATING %
BHP @ RATING FOR SP. GR. (1):
MAX. BHP W/IMPELLER SUPPLIED FOR SP. GR. (1):
MAX. BHP W/MAX. IMPELLER FOR SP. GR. (1):

### CONSTRUCTION

CASE: SWP (2) PSIG @ °F.; HYDTEST. PSIG
MIN. THICKNESS ", CORR. ALLOW. "
SUPPORT TYPE: (CENTERLINE; FOOT; BRACKET)
IMPELLER OVERHUNG: (YES; NO)
SPLIT: (HORIZONTAL; VERTICAL; BARREL)
INSULATION
IMPELLER DIAM: SUPPLIED "; MAX. "; MIN. "
TYPE: (OPEN; SEMI-ENCLOSED; ENCLOSED)
EYE VELOCITY @ RATING FT./SEC.
DIRECTION OF ROTATION (FACING PUMP COUPLING) (CW; CCW)
CLEARANCE (RADIAL) WEARING RINGS "
INTERSTG. PIECE "; PRESS. RED. DRUM "
COUPLING, FLEXIBLE: (SINGLE; SPACER; FLOATING)
SLEEVE TYPE: ADJUSTABLE: (YES; NO)
MFGR.
GUARD
STUFFING BOXES: BORE "; DEPTH "
JACKETED (YES; NO)
PACKING TYPE (3)
SIZE: " I.D.: " O.D.: " SQ
NUMBER OF RINGS
MECHANICAL SEAL
SMOTHERING GLAND: (YES; NO)
FLUSHING OIL TO: LANTRN RING: (YES; NO); WEAR. RING: (YES; NO)
BASE PLATE TYPE
FLOOR SPACE REQ'D.

BEARINGS: THRUST: TYPE: (BALL; STEP; KINGSB.) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:
RADIAL: TYPE: (BALL; SLEEVE) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:

| MFGR. SHALL SUPPLY THE FOLLOWING | DRAWING NO. |
|---|---|
| SERIAL NUMBER |  |
| PERFORMANCE CURVES (CALCULATED; TEST) (NOTE 5) |  |
| OUTLINE DRAWING |  |
| CROSS SECTION DRAWING |  |
| NAME PLATE: PERMANENT METAL LABEL WITH ITEM NO. AND SERVICE SHOWN ABOVE. DESIGN GPM DIFF. HEAD |  |

| NOZZLES | SIZE | RATING (4) | FACING (4) | LOCATION |
|---|---|---|---|---|
| SUCTION |  |  |  |  |
| DISCHARGE |  |  |  |  |
| VENTS |  |  |  |  |
| DRAINS |  |  |  |  |
| COOLING WATER |  |  |  |  |

|  |  |
|---|---|
| C.W. TO: BEAR'GS: THR: (YES; NO) GPM | WT. OF PUMP LBS. |
| BEAR'GS: RAD: (YES; NO) GPM | WT. OF PUMP AND BASE LBS. |
| STUFF. BOX: (YES; NO) GPM | WT. OF DRIVER LBS. |
| PEDESTAL: (YES; NO) GPM | SHIPPING WT. LBS. |

WITNESS TEST
STATIC BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)
DYNAM. BALANC'G. OF. IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)

DRIVER: SUPPLIED BY MOUNTED BY

| | | |
|---|---|---|
| ELEC. MOTOR, MAKE | TURBINE, MAKE | ENGINE, MAKE |
| TYPE | TYPE | TYPE ; H.P. |
| SPECIAL INSULATION | H.P. | FUEL |
| H.P. ; RPM | PRESS. @ THROTTLE PSIG | HEATING VALUE LHV. |
| VOLTS ; PH. ; CYC. | TEMPERATURE °F. | FUEL CONSUMPTION BTU/BHP./HR. |
| START: (LOW VOLTAGE; ACROSS LINE) | QUALITY OR SUPERHEAT | SPEED: OPER. RPM; MAX. ALLOW RPM |
| BEARINGS | BACK PRESS PSIG | SPEED REDUCER: (V-BELT; GEAR) |
| BEARINGS LUB. | WATER RATE LBS./H.P. HR. | VENDOR SUPPLY: SPEED REDUCER, MUFFLER, RADIATOR, GENERATOR |
| POWER CONSUMPTION | MAX. ALLOW. SPEED RPM | STARTER, AIR CLEANER, OIL FILTER, FUEL REG., BATTERY |

REMARKS * Vertical Cantilever Type 4' Long Shaft; 2' Long Tail Piece

(1) FOR A RANGE OF SP. GR., USE LOWEST FOR IMPELLER SIZING AND DESIGN HEAD, HIGHEST FOR H. P. CALC.
(2) CASE SAFE WORKING PRESS. SHALL BE GIVEN AFTER SUBTRACT. CORROS. ALLOW
(3) PACKING WILL BE INSTALLED IN FIELD. VENDOR TO SHIP IN INDIVIDUAL LABELLED PACKAGES.
(4) RATE PER ASA B16E LATEST SUPPLEMENT.
(5) PERFORM. CURVES MUST INCLUDE: HEAD, CAPACITY, EFFIC., BHP, REQ'D NPSH FOR DESIGN IMPELLER; ALSO HEAD, CAPACITY FOR MIN. AND MAX. IMPELLERS.

## CENTRIFUGAL PUMP SPECIFICATION
## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING

SHEET NO. 2 REV.
DATE 11-16-70
BY SF CHK'D.
JOB NO. PS-218
MFR'S TYPE NO.

P-2A, 2A(S)
P-2B, 2B(S)
ITEM NO.
SERVICE Reducer Pumps
NO. REQ'D. 4 MOTOR DRIVEN, AND DRIVEN. VENDOR

LIQUID PUMPED Molten Carbonate Salt
CORROSION OR EROSION FACTORS

### OPERATING CONDITIONS

PUMPING TEMPERATURE 950 °F.

| | | | |
|---|---|---|---|
| FLOW @ P.T. | 585 GPM | DIFFERENTIAL | 156 PSI FT. (1) |
| SPEC. GR. @ P.T. | 2.0 | DISCHARGE | PSIG |
| VISCOS. @ P.T. | 12 C.P. | SUCTION | PSIG |
| | | BAROMETRIC | PSIA |
| | | NPSH AVAILABLE | FT. |
| | | NPSH REQUIRED | FT. |

### MATERIALS

| MATERIALS | | BRINNELL HARDNESS OF WEAR'G PARTS |
|---|---|---|
| CASE: INNER | | |
| OUTER | All Wetted Parts | |
| WEAR RINGS | To Be S.S. Type 347 | |
| STUDS AND NUTS | | |
| GASKETS | | |
| IMPELLER | | |
| WEAR RINGS | | |
| DIFFUSERS | | |
| INTERSTG. PIECE | | |
| INTERSTG. BUSHING | | |
| SHAFT | | |
| STUFF. BOX SHAFT SLEEVES | | |
| INTERSTG. SHAFT SLEEVE | | |
| STUFFING BOX | | |
| PACKING GLAND | | |
| GLAND STUDS | | |
| LANTERN RING | | |
| THROAT BUSHING | | |
| BALANCING DRUM | | |
| PRESS. BAL. SLEEVE | | |
| BEARING HOUSING | | |

Reproduced from best available copy.

PUMP TYPE:* (HORIZ; VERT. SUBMERG; VERT. SUCT.; REGEN. TURB.)
PUMP SIZE ; NO. OF STAGES ; SPEED RPM
HYDRAULIC H.P. EFFICIENCY @ RATING %
BHP @ RATING FOR SP. GR. (1):
MAX. BHP W/IMPELLER SUPPLIED FOR SP. GR. (1):
MAX. BHP W/MAX. IMPELLER FOR SP. GR. (1):

### CONSTRUCTION

CASE: SWP (2) PSIG @ °F.; HYDTEST. PSIG
MIN. THICKNESS ", CORR. ALLOW. "
SUPPORT TYPE: (CENTERLINE; FOOT; BRACKET)
IMPELLER OVERHUNG: (YES; NO)
SPLIT: (HORIZONTAL; VERTICAL; BARREL)
INSULATION
IMPELLER DIAM: SUPPLIED "; MAX. "; MIN. "
TYPE: (OPEN; SEMI-ENCLOSED; ENCLOSED)
EYE VELOCITY @ RATING FT./SEC.
DIRECTION OF ROTATION (FACING PUMP COUPLING) (CW; CCW)
CLEARANCE (RADIAL) WEARING RINGS "
INTERSTG. PIECE "; PRESS. RED. DRUM "
COUPLING, FLEXIBLE: (SINGLE; SPACER; FLOATING)
SLEEVE TYPE: ADJUSTABLE: (YES; NO)
MFGR.
GUARD
STUFFING BOXES: BORE "; DEPTH "
JACKETED (YES; NO)
PACKING TYPE (3)
SIZE: " I.D.: " O.D.: " SQ.
NUMBER OF RINGS
MECHANICAL SEAL
SMOTHERING GLAND: (YES; NO)
FLUSHING OIL TO: LANTRN RING: (YES; NO); WEAR. RING: (YES; NO)
BASE PLATE TYPE
FLOOR SPACE REQ'D.

BEARINGS: THRUST: TYPE: (BALL; STEP; KINGSB.) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:
RADIAL: TYPE: (BALL; SLEEVE) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:

| MFGR. SHALL SUPPLY THE FOLLOWING | DRAWING NO. |
|---|---|
| SERIAL NUMBER | |
| PERFORMANCE CURVES (CALCULATED; TEST) (NOTE 5) | |
| OUTLINE DRAWING | |
| CROSS SECTION DRAWING | |
| NAME PLATE: PERMANENT METAL LABEL WITH ITEM NO. AND SERVICE SHOWN ABOVE. DESIGN GPM DIFF. HEAD | |

| NOZZLES | SIZE | RATING (4) | FACING (4) | LOCATION |
|---|---|---|---|---|
| SUCTION | | | | |
| DISCHARGE | | | | |
| VENTS | | | | |
| DRAINS | | | | |
| COOLING WATER | | | | |

| | | |
|---|---|---|
| C.W. TO: BEAR'GS: THR: (YES; NO) GPM | WT. OF PUMP LBS. | WITNESS TEST |
| BEAR'GS: RAD: (YES; NO) GPM | WT. OF PUMP AND BASE LBS. | |
| STUFF. BOX: (YES; NO) GPM | WT. OF DRIVER LBS. | STATIC BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO) |
| PEDESTAL: (YES; NO) GPM | SHIPPING WT. LBS. | DYNAM. BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO) |

DRIVER: SUPPLIED BY MOUNTED BY

| | | |
|---|---|---|
| ELEC. MOTOR, MAKE | TURBINE, MAKE | ENGINE, MAKE |
| TYPE | TYPE | TYPE ; H.P. |
| SPECIAL INSULATION | H.P. | FUEL |
| H.P. ; RPM | PRESS. @ THROTTLE PSIG | HEATING VALUE LHV |
| VOLTS ; PH. ; CYC. | TEMPERATURE °F. | FUEL CONSUMPTION BTU/BHP/HR |
| START: (LOW VOLTAGE; ACROSS LINE) | QUALITY OR SUPERHEAT | SPEED: OPER. RPM; MAX. ALLOW RPM |
| BEARINGS | BACK PRESS PSIG | SPEED REDUCER (V-BELT; GEAR) |
| BEARINGS LUB. | WATER RATE LBS./H.P. HR. | VENDOR SUPPLY: SPEED REDUCER, MUFFLER, RADIATOR, GENERATOR |
| POWER CONSUMPTION | MAX. ALLOW. SPEED RPM | STARTER, AIR CLEANER, OIL FILTER, FUEL REG., BATTERY |

REMARKS *Vertical Cantilever Type 4' Long Shaft-4' Long Tail Piece

(1) FOR A RANGE OF SP. GR., USE LOWEST FOR IMPELLER SIZING AND DESIGN HEAD, HIGHEST FOR H. P. CALC.
(2) PACKING WILL BE INSTALLED IN FIELD, VENDOR TO SHIP IN INDIVIDUAL LABELLED PACKAGES.
(3) PERFORM. CURVES MUST INCLUDE: HEAD, CAPACITY, EFFIC., BHP, REQ'D NPSH FOR DESIGN IMPELLER; ALSO HEAD, CAPACITY FOR MIN. AND MAX. IMPELLERS.
(2) CASE SAFE WORKING PRESS. SHALL BE GIVEN AFTER SUBTRACT. CORROS. ALLOW.
(4) RATE PER ASA RISE LATEST SUPPLEMENT.

## CENTRIFUGAL PUMP SPECIFICATION
## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING

SHEET NO. 3 REV.
DATE 11-16-70
BY SF CHK'D.
JOB NO. PS-218
MFR'S TYPE NO.

P-3, .3 (S)
ITEM NO. SERVICE Regenerator Bottoms Pump
NO. REQ'D. 2 MOTOR DRIVEN, AND DRIVEN. VENDOR
LIQUID PUMPED Molten Carbonate Salt
CORROSION OR EROSION FACTORS

**OPERATING CONDITIONS**

PUMPING TEMPERATURE 950 °F.
FLOW @ P.T. 300 GPM
SPEC. GR. @ P.T. 210
VISCOS. @ P.T. 12 C.P.
DIFFERENTIAL 147 PSI 171 FT. (1)
DISCHARGE 147 PSIG
SUCTION 0 PSIG
BAROMETRIC PSIA
NPSH AVAILABLE FT.
NPSH REQUIRED FT.

**MATERIALS** — BRINNELL HARDNESS OF WEAR'G PARTS

CASE: INNER
OUTER All Wetted Parts
WEAR RINGS SS Type 347
STUDS AND NUTS
GASKETS
IMPELLER
WEAR RINGS
DIFFUSERS
INTERSTG. PIECE
INTERSTG. BUSHING
SHAFT
STUFF. BOX SHAFT SLEEVES
INTERSTG. SHAFT SLEEVE
STUFFING BOX
PACKING GLAND
GLAND STUDS
LANTERN RING
THROAT BUSHING
BALANCING DRUM
PRESS. BAL. SLEEVE
BEARING HOUSING

PUMP TYPE:* (HORIZ: VERT. SUBMERG: VERT. SUCT.: REGEN. TURB.)
PUMP SIZE ; NO. OF STAGES : SPEED RPM
HYDRAULIC H.P. EFFICIENCY @ RATING %
BHP @ RATING FOR SP. GR. (1):
MAX. BHP W/IMPELLER SUPPLIED FOR SP. GR. (1):
MAX. BHP W/MAX. IMPELLER FOR SP. GR. (1):

**CONSTRUCTION**

CASE: SWP (2) PSIG @ °F.: HYDTEST. PSIG
MIN. THICKNESS ". CORR. ALLOW. "
SUPPORT TYPE: (CENTERLINE: FOOT: BRACKET)
IMPELLER OVERHUNG: (YES: NO)
SPLIT: (HORIZONTAL: VERTICAL: BARREL)
INSULATION
IMPELLER DIAM: SUPPLIED "; MAX. "; MIN. "
TYPE: (OPEN: SEMI-ENCLOSED: ENCLOSED)
EYE VELOCITY @ RATING FT./SEC
DIRECTION OF ROTATION (FACING PUMP COUPLING) (CW: CCW)
CLEARANCE (RADIAL) WEARING RINGS "
INTERSTG. PIECE "; PRESS. RED. DRUM "
COUPLING. FLEXIBLE: (SINGLE: SPACER: FLOATING)
SLEEVE TYPE: ADJUSTABLE: (YES: NO)
MFGR.
GUARD
STUFFING BOXES: BORE "; DEPTH "
JACKETED (YES: NO)
PACKING TYPE (3)
SIZE " I.D.: " O.D.: " SQ
NUMBER OF RINGS
MECHANICAL SEAL
SMOTHERING GLAND: (YES: NO)
FLUSHING OIL TO: LANTRN RING: (YES: NO): WEAR. RING: (YES: NO)
BASE PLATE TYPE
FLOOR SPACE REQ'D.

BEARINGS: THRUST: TYPE: (BALL: STEP: KINGSB.) TYPE NO. ; LUBRICATORS (OIL: GREASE) TYPE: CAP:
RADIAL: TYPE: (BALL: SLEEVE) TYPE NO. ; LUBRICATORS (OIL: GREASE) TYPE: CAP:

MFGR. SHALL SUPPLY THE FOLLOWING DRAWING NO.
SERIAL NUMBER
PERFORMANCE CURVES (CALCULATED: TEST) (NOTE 5)
OUTLINE DRAWING
CROSS SECTION DRAWING
NAME PLATE: PERMANENT METAL LABEL WITH ITEM NO. AND SERVICE SHOWN ABOVE. DESIGN GPM DIFF. HEAD

| NOZZLES | SIZE | RATING (4) | FACING (4) | LOCATION |
|---|---|---|---|---|
| SUCTION | | | | |
| DISCHARGE | | | | |
| VENTS | | | | |
| DRAINS | | | | |
| COOLING WATER | | | | |

C.W. TO: BEAR'GS: THR: (YES: NO) GPM
BEAR'GS: RAD: (YES: NO) GPM
STUFF. BOX: (YES: NO) GPM
PEDESTAL: (YES: NO) GPM
WT. OF PUMP LBS.
WT. OF PUMP AND BASE LBS.
WT. OF DRIVER LBS.
SHIPPING WT. LBS.
WITNESS TEST
STATIC BALANC'G. OF: IMP.: (YES: NO): ROTAT'G. ASSBY.: (YES: NO)
DYNAM. BALANC'G. OF: IMP.: (YES: NO): ROTAT'G. ASSBY.: (YES: NO)

DRIVER: SUPPLIED BY MOUNTED BY

ELEC. MOTOR, MAKE
TYPE
SPECIAL INSULATION
H.P. ; RPM
VOLTS ; PH. ; CYC.
START: (LOW VOLTAGE: ACROSS LINE)
BEARINGS
BEARINGS LUB.
POWER CONSUMPTION

TURBINE, MAKE
TYPE
H.P.
PRESS. @ THROTTLE PSIG
TEMPERATURE °F.
QUALITY OR SUPERHEAT
BACK PRESS PSIG
WATER RATE LBS./H.P. HR.
MAX. ALLOW. SPEED RPM

ENGINE, MAKE
TYPE ; H.P.
FUEL
HEATING VALUE LHV
FUEL CONSUMPTION BTU/BHP/HR
SPEED: OPER. RPM; MAX. ALLOW RPM
SPEED REDUCER (V-BELT: GEAR)
VENDOR SUPPLY: SPEED REDUCER, MUFFLER, RADIATOR, GENERATOR, STARTER, AIR CLEANER, OIL FILTER, FUEL REG., BATTERY

REMARKS * Vertical Cantilever Type - 4' Long Shaft-2' Long Tail Piece

(1) FOR A RANGE OF SP. GR., USE LOWEST FOR IMPELLER SIZING AND DESIGN HEAD, HIGHEST FOR H. P. CALC.
(2) CASE SAFE WORKING PRESS. SHALL BE GIVEN AFTER SUBTRACT. CORROS. ALLOW.
(3) PACKING WILL BE INSTALLED IN FIELD. VENDOR TO SHIP IN INDIVIDUAL LABELLED PACKAGES.
(4) RATE PER ASA BISE LATEST SUPPLEMENT.
(5) PERFORM. CURVES MUST INCLUDE: HEAD, CAPACITY, EFFIC., BHP, REQ'D NPSH FOR DESIGN IMPELLER; ALSO HEAD, CAPACITY FOR MIN AND MAX. IMPELLERS.

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P-4, .4 (S)

# CENTRIFUGAL PUMP SPECIFICATION
## SINGMASTER & BREYER

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING

SHEET NO. 4 REV.
DATE 11-16-70
BY SF CHK'D.
JOB NO. PS-218
MFR'S TYPE NO.

ITEM NO.
SERVICE Regenerator Intermediate Pump
NO. REQ'D. 2 MOTOR DRIVEN, AND DRIVEN. VENDOR

LIQUID PUMPED Molten Carbonate Salt
CORROSION OR EROSION FACTORS

### OPERATING CONDITIONS

PUMPING TEMPERATURE 950 °F.
FLOW @ P.T. 350 GPM
SPEC. GR. @ P.T. 2.0
VISCOS. @ P.T. 12 C.P.
DIFFERENTIAL 101 PSI 117 FT. (1)
DISCHARGE 101 PSIG
SUCTION 0 PSIG
BAROMETRIC PSIA
NPSH AVAILABLE FT.
NPSH REQUIRED FT.

### MATERIALS

| | | BRINNELL HARDNESS OF WEAR'S PARTS |
|---|---|---|
| CASE: INNER | | |
| OUTER | All Wetted Parts | |
| WEAR RINGS | SS Type 347 | |
| STUDS AND NUTS | | |
| GASKETS | | |
| IMPELLER | | |
| WEAR RINGS | | |
| DIFFUSERS | | |
| INTERSTG. PIECE | | |
| INTERSTG. BUSHING | | |
| SHAFT | | |
| STUFF. BOX SHAFT SLEEVES | | |
| INTERSTG. SHAFT SLEEVE | | |
| STUFFING BOX | | |
| PACKING GLAND | | |
| GLAND STUDS | | |
| LANTERN RING | | |
| THROAT BUSHING | | |
| BALANCING DRUM | | |
| PRESS. BAL. SLEEVE | | |
| BEARING HOUSING | | |

Reproduced from best available copy.

PUMP TYPE:* (HORIZ: VERT. SUBMERG: VERT. SUCT.; REGEN. TURB.)
PUMP SIZE ; NO. OF STAGES ; SPEED RPM
HYDRAULIC H.P. EFFICIENCY @ RATING %
BHP @ RATING FOR SP. GR. (1):
MAX. BHP W/IMPELLER SUPPLIED FOR SP. GR. (1):
MAX. BHP W/MAX. IMPELLER FOR SP. GR. (1):

### CONSTRUCTION

CASE: SWP (2) PSIG @ °F.; HYDTEST. PSIG
MIN. THICKNESS ", CORR. ALLOW. "
SUPPORT TYPE: (CENTERLINE; FOOT; BRACKET)
IMPELLER OVERHUNG: (YES; NO)
SPLIT: (HORIZONTAL; VERTICAL; BARREL)
INSULATION
IMPELLER DIAM: SUPPLIED "; MAX. "; MIN. "
TYPE: (OPEN; SEMI-ENCLOSED; ENCLOSED)
EYE VELOCITY @ RATING FT./SEC
DIRECTION OF ROTATION (FACING PUMP COUPLING) (CW; CCW)
CLEARANCE (RADIAL) WEARING RINGS "
INTERSTG. PIECE "; PRESS. RED. DRUM "
COUPLING, FLEXIBLE: (SINGLE; SPACER; FLOATING)
SLEEVE TYPE: ADJUSTABLE: (YES; NO)
MFGR.
GUARD
STUFFING BOXES: BORE "; DEPTH "
JACKETED (YES; NO)
PACKING TYPE (3)
SIZE: " I.D.: " O.D.: " SQ.
NUMBER OF RINGS
MECHANICAL SEAL
SMOTHERING GLAND: (YES; NO)
FLUSHING OIL TO: LANTRN RING: (YES; NO); WEAR. RING: (YES; NO)
BASE PLATE TYPE
FLOOR SPACE REQ'D.

BEARINGS: THRUST: TYPE: (BALL; STEP; KINGSB.) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:
RADIAL: TYPE: (BALL; SLEEVE) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:

| MFGR. SHALL SUPPLY THE FOLLOWING | DRAWING NO. |
|---|---|
| SERIAL NUMBER | |
| PERFORMANCE CURVES (CALCULATED; TEST) (NOTE 5) | |
| OUTLINE DRAWING | |
| CROSS SECTION DRAWING | |
| NAME PLATE: PERMANENT METAL LABEL WITH ITEM NO. AND SERVICE SHOWN ABOVE. DESIGN GPM DIFF. HEAD | |

| NOZZLES | SIZE | RATING (4) | FACING (4) | LOCATION |
|---|---|---|---|---|
| SUCTION | | | | |
| DISCHARGE | | | | |
| VENTS | | | | |
| DRAINS | | | | |
| COOLING WATER | | | | |

C.W. TO: BEAR'GS: THR: (YES; NO) GPM
BEAR'GS: RAD: (YES; NO) GPM
STUFF. BOX: (YES; NO) GPM
PEDESTAL: (YES; NO) GPM

WT. OF PUMP LBS.
WT. OF PUMP AND BASE LBS.
WT. OF DRIVER LBS.
SHIPPING WT. LBS.

WITNESS TEST
STATIC BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)
DYNAM. BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)

DRIVER: SUPPLIED BY MOUNTED BY

| | | |
|---|---|---|
| ELEC. MOTOR, MAKE | TURBINE, MAKE | ENGINE, MAKE |
| TYPE | TYPE | TYPE ; H.P. |
| SPECIAL INSULATION | H.P. | FUEL |
| H.P. ; RPM | PRESS. @ THROTTLE PSIG | HEATING VALUE LHV. |
| VOLTS ; PH. ; CYC. | TEMPERATURE °F. | FUEL CONSUMPTION BTU/BHP/HR |
| START: (LOW VOLTAGE; ACROSS LINE) | QUALITY OR SUPERHEAT | SPEED: OPER. RPM; MAX. ALLOW RPM |
| BEARINGS | BACK PRESS PSIG | SPEED REDUCER: (V-BELT; GEAR) |
| BEARINGS LUB. | WATER RATE LBS./H.P. HR. | VENDOR SUPPLY: SPEED REDUCER, MUFFLER, RADIATOR, GENERATOR |
| POWER CONSUMPTION | MAX. ALLOW. SPEED RPM | STARTER, AIR CLEANER, OIL FILTER, FUEL REG., BATTERY |

REMARKS *Vertical Cantilever Type 4' Long Shaft; 2' Long Tail Piece

(1) FOR A RANGE OF SP. GR., USE LOWEST FOR IMPELLER SIZING AND DESIGN HEAD, HIGHEST FOR H. P. CALC.
(3) PACKING WILL BE INSTALLED IN FIELD. VENDOR TO SHIP IN INDIVIDUAL LABELLED PACKAGES.
(5) PERFORM. CURVES MUST INCLUDE: HEAD, CAPACITY, EFFIC., BHP. REQ'D NPSH FOR DESIGN IMPELLER; ALSO HEAD, CAPACITY FOR MIN. AND MAX. IMPELLERS.
(2) CASE SAFE WORKING PRESS. SHALL BE GIVEN AFTER SUBTRACT. CORROS. ALLOW
(4) RATE PER ASA BISE LATEST SUPPLEMENT.

# CENTRIFUGAL PUMP SPECIFICATION
# SINGMASTER & BREYER

SHEET NO. 5 REV.
DATE 11-16-70
BY SF . CHK'D.
JOB NO. PS-218
MFR'S TYPE NO.

VENDOR MUST COMPLETE THIS SPECIFICATION SHEET BEFORE RETURNING

ITEM NO. P-5 SERVICE $M_2CO_3$ Makeup Pump
NO. REQ'D. 1 MOTOR DRIVEN, AND DRIVEN. VENDOR
LIQUID PUMPED Molten Carbonate Salts
CORROSION OR EROSION FACTORS

## OPERATING CONDITIONS

PUMPING TEMPERATURE 800 °F.
FLOW @ P.T. 4 GPM
SPEC. GR. @ P.T. 2.0
VISCOS. @ P.T. 12 C.P.
DIFFERENTIAL 12 PSI 14 FT. (1)
DISCHARGE 12 PSIG
SUCTION 0 PSIG
BAROMETRIC PSIA
NPSH AVAILABLE FT.
NPSH REQUIRED FT.

PUMP TYPE: * (HORIZ: VERT. SUBMERG; VERT. SUCT.; REGEN. TURB.)
PUMP SIZE ; NO. OF STAGES ; SPEED RPM
HYDRAULIC H.P. EFFICIENCY @ RATING %
BHP @ RATING FOR SP. GR. (1):
MAX. BHP W/IMPELLER SUPPLIED FOR SP. GR. (1):
MAX. BHP W/MAX. IMPELLER FOR SP. GR. (1):

## MATERIALS

| MATERIALS | BRINNELL HARDNESS OF WEAR'G PARTS |
|---|---|
| CASE: INNER | |
| OUTER All Wetted Parts | |
| WEAR RINGS Type 347 SS | |
| STUDS AND NUTS | |
| GASKETS | |
| IMPELLER | |
| WEAR RINGS | |
| DIFFUSERS | |
| INTERSTG. PIECE | |
| INTERSTG. BUSHING | |
| SHAFT | |
| STUFF. BOX SHAFT SLEEVES | |
| INTERSTG. SHAFT SLEEVE | |
| STUFFING BOX | |
| PACKING GLAND | |
| GLAND STUDS | |
| LANTERN RING | |
| THROAT BUSHING | |
| BALANCING DRUM | |
| PRESS. BAL. SLEEVE | |
| BEARING HOUSING | |

## CONSTRUCTION

CASE: SWP (2) PSIG @ °F.; HYDTEST. PSIG
MIN. THICKNESS ", CORR. ALLOW. "
SUPPORT TYPE: (CENTERLINE; FOOT; BRACKET)
IMPELLER OVERHUNG: (YES; NO)
SPLIT: (HORIZONTAL; VERTICAL; BARREL)
INSULATION
IMPELLER DIAM: SUPPLIED "; MAX. "; MIN. ".
TYPE: (OPEN; SEMI-ENCLOSED; ENCLOSED)
EYE VELOCITY @ RATING FT./SEC.
DIRECTION OF ROTATION (FACING PUMP COUPLING) (CW; CCW)
CLEARANCE (RADIAL) WEARING RINGS "
INTERSTG. PIECE "; PRESS. RED. DRUM "
COUPLING, FLEXIBLE: (SINGLE; SPACER; FLOATING)
SLEEVE TYPE: ADJUSTABLE; (YES; NO)
MFGR.
GUARD
STUFFING BOXES: BORE "; DEPTH "
JACKETED (YES; NO)
PACKING TYPE (3)
SIZE: " I.D.: " O.D.: " SQ.
NUMBER OF RINGS
MECHANICAL SEAL
SMOTHERING GLAND: (YES; NO)
FLUSHING OIL TO: LANTRN RING: (YES; NO); WEAR. RING: (YES; NO)
BASE PLATE TYPE
FLOOR SPACE REQ'D.

BEARINGS: THRUST: TYPE: (BALL; STEP; KINGSB.) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:
RADIAL: TYPE: (BALL; SLEEVE) TYPE NO. ; LUBRICATORS (OIL; GREASE) TYPE: CAP:

| MFGR. SHALL SUPPLY THE FOLLOWING | DRAWING NO. |
|---|---|
| SERIAL NUMBER | |
| PERFORMANCE CURVES (CALCULATED; TEST) (NOTE 5) | |
| OUTLINE DRAWING | |
| CROSS SECTION DRAWING | |
| NAME PLATE: PERMANENT METAL LABEL WITH ITEM NO. AND SERVICE SHOWN ABOVE. DESIGN GPM DIFF. HEAD | |

| NOZZLES | SIZE | RATING (4) | FACING (4) | LOCATION |
|---|---|---|---|---|
| SUCTION | | | | |
| DISCHARGE | | | | |
| VENTS | | | | |
| DRAINS | | | | |
| COOLING WATER | | | | |

C.W. TO: BEAR'GS: THR: (YES; NO) GPM
BEAR'GS: RAD: (YES; NO) GPM
STUFF. BOX: (YES; NO) GPM
PEDESTAL: (YES; NO) GPM

WT. OF PUMP LBS.
WT. OF PUMP AND BASE LBS.
WT. OF DRIVER LBS.
SHIPPING WT. LBS.

WITNESS TEST
STATIC BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)
DYNAM. BALANC'G. OF: IMP.: (YES; NO); ROTAT'G. ASSBY.: (YES; NO)

DRIVER: SUPPLIED BY
MOUNTED BY

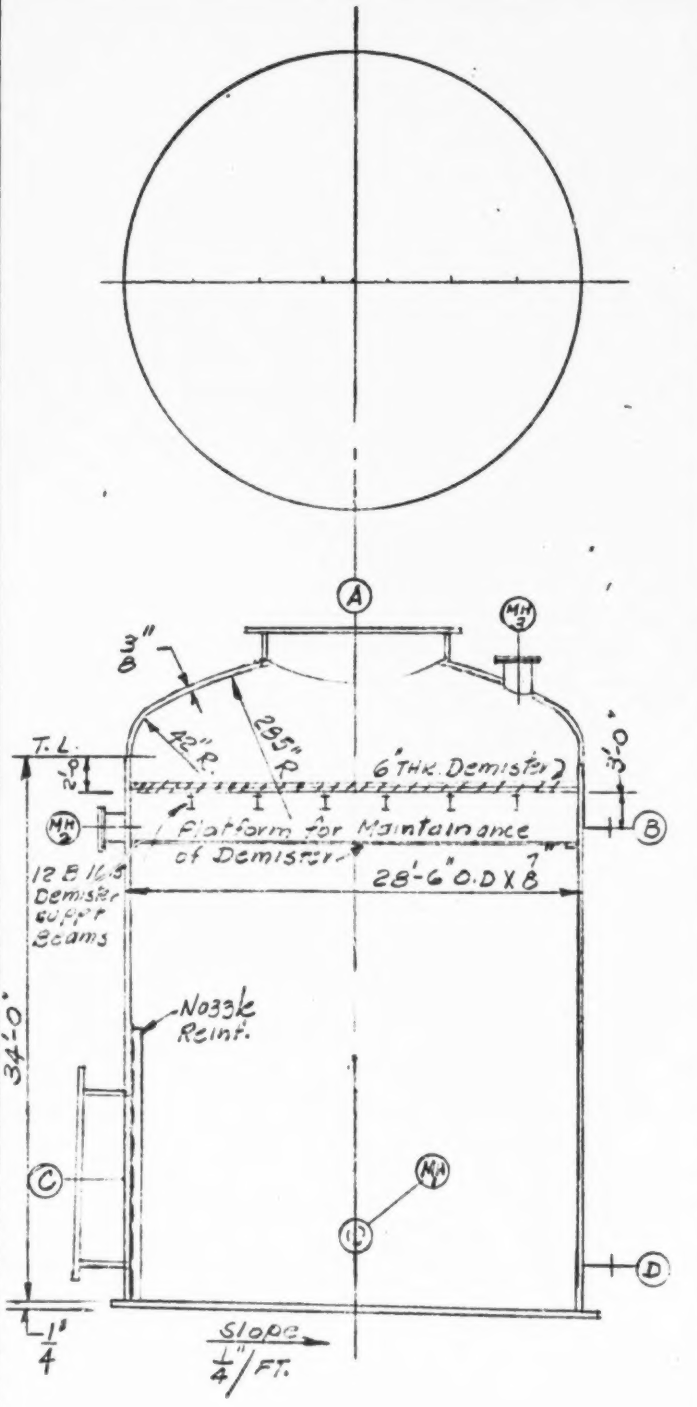
| ELEC. MOTOR, MAKE | TURBINE, MAKE | ENGINE, MAKE |
|---|---|---|
| TYPE | TYPE | TYPE ; H.P. |
| SPECIAL INSULATION | H.P. | FUEL |
| H.P. ; RPM | PRESS. @ THROTTLE PSIG | HEATING VALUE LHV. |
| VOLTS ; PH. ; CYC. | TEMPERATURE °F. | FUEL CONSUMPTION BTU/BHP./HR |
| START: (LOW VOLTAGE; ACROSS LINE) | QUALITY OR SUPERHEAT | SPEED: OPER. RPM: MAX. ALLOW RPM |
| BEARINGS | BACK PRESS PSIG | SPEED REDUCER: (V-BELT; GEAR) |
| BEARINGS LUB. | WATER RATE LBS./H.P. HR. | VENDOR SUPPLY: SPEED REDUCER, MUFFLER, RADIATOR, GENERATOR |
| POWER CONSUMPTION | MAX. ALLOW. SPEED RPM | STARTER, AIR CLEANER, OIL FILTER, FUEL REG., BATTERY |

REMARKS * Vertical Cantilever Type - 3' Long Shaft; 2' Long Tail Piece

(1) FOR A RANGE OF SP. GR., USE LOWEST FOR IMPELLER SIZING AND DESIGN HEAD, HIGHEST FOR H. P. CALC.
(2) CASE SAFE WORKING PRESS. SHALL BE GIVEN AFTER SUBTRACT. CORROS. ALLOW.
(3) PACKING WILL BE INSTALLED IN FIELD. VENDOR TO SHIP IN INDIVIDUAL LABELLED PACKAGES.
(4) RATE PER ASA DISC LATEST SUPPLEMENT.
(5) PERFORM. CURVES MUST INCLUDE: HEAD, CAPACITY, EFFIC., BHP, REQ'D NPSH FOR DESIGN IMPELLER; ALSO HEAD, CAPACITY FOR MIN. AND MAX. IMPELLERS.

### c. Vessel Sketches

Sketches of vessels, tanks or bins required for the $SO_x$ removal process that are not provided with major equipment are attached to this section of the report.


A
MH 3
3"/8
42" R.
295" R
T.L.
2'-9"
6" THK. Demister
3'-0"
MH 2
B
Platform for Maintainance of Demister
12 B 16.5 Demister Suppt Beams
28'-6" O.D X 7/8"
34'-0"
Nozzle Reinf.
C
MH 1
D
1/4"
Slope 1/4"/FT.

Added CONN. D.
CONN B WAS 3"

4 Req'd

BY BL
DATE 9.14.73
CHK'D
APP'D

ABSORBER
V-1A, B, C, & D

## VESSEL DESIGN DATA

| | | |
|---|---|---|
| CODE STAMP No-API-650 [illegible] | | |
| OTHER SPECS.: SP[redacted] | | |
| DESIGN PRESS. @ TEMP. | 1 PSI @ | 950 °F |
| OPER. PRESS. @ TEMP. | ½ PSI @ | 850 °F |
| STRESS RELIEVING | | |
| WELD EXAMINATION | | |
| JOINT EFFICIENCY | SHELL % | HEADS % |
| | | |
| CORR. ALLOWANCE | SHELL | HEADS |
| LINING | | |
| MAX. ALL. PRESS. (NEW & COLD) | | PSI |
| HYDROSTATIC TEST | | PSI |
| HAMMER TEST | | PSI |

| | | |
|---|---|---|
| MATERIALS | SHELL | A-240 TP 347 |
| | HEADS | A-240 TP 347 |
| | SUPPORT | |
| | INTERNALS | A-240 TP347 |
| | TRAYS | |
| | | |

S.G. = 2.0 Liq. Level = 0'

| | | | |
|---|---|---|---|
| FIREPROOFING | THK. | | SQ.FT. |
| INSULATION | THK. | | SQ.FT. |
| INS. SUPP. RINGS | | | |
| PAINT | | | |
| WT. OF TRAYS | FURN. BY | | |
| | INST'D BY | | LBS. |
| WT. & NO. OF CAPS | FURN. BY | | REQ'D. |
| | INST'D BY | | LBS. |
| NET FAB. WT. (LESS TRAYS AND CAPS) | | 193,400 | LBS. |
| FOUNDATION DATA | EMPTY WEIGHT | 205,000 | LBS. |
| | OPERATING WEIGHT | | LBS. |
| | TEST WEIGHT | 1,560,000 | LBS. |
| | WIND $M_B$ = | | FT.LBS. |
| | EARTHQUAKE $M_B$ = | | FT.LBS. |
| MANHOLE (HINGED OR DAVITED) | | | |
| HANDHOLE | | | |
| NOTES & REF. DWGS.: | | | |

## NOZZLE SCHEDULE

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| A | | | 132" | |
| B | | | 8" | |
| C | | | 132" | |
| MH 1,2,3 | | | 18 | Manholes |
| D | | | 10" | Liquid Outlet |
| | | | | |
| | | | | |
| | | | | |

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

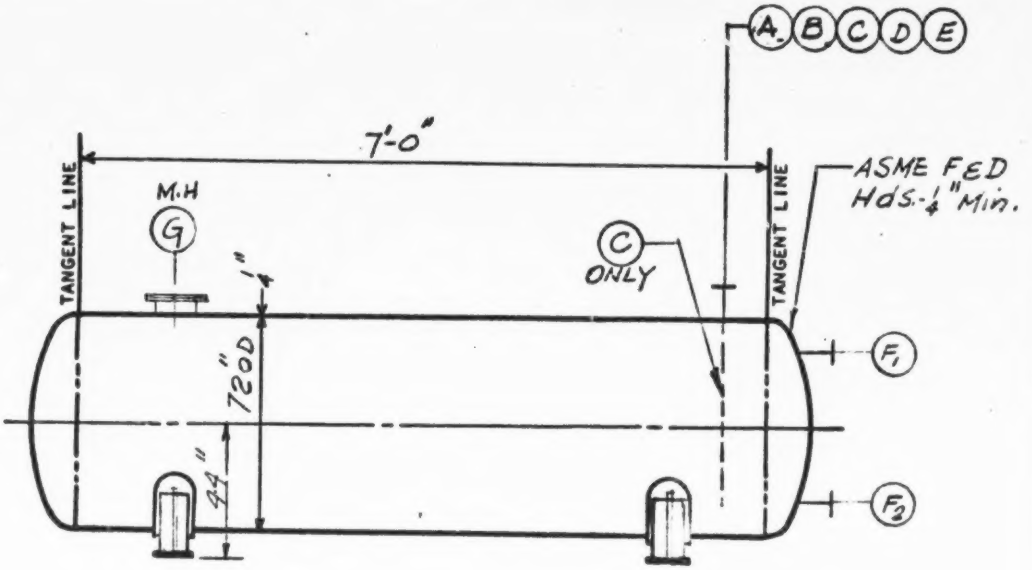
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PLAT-FORMS | NO. | | | | NO. PIPE SUPPORT CLIPS | TYPE I | |
| | SIZE | | | | | TYPE II | |
| | WIDTH | | | | | TYPE III | |
| PLATFORM WEIGHT | | | | | VESSEL DAVIT | | |

LADDER CAGE WT.

PIPE GUIDES 3000# 1/2 CPLGS.

CONTRACT NO. DWG. NO.
PS-218-4009 0A

SINGMASTER & BREYER



3 REQUIRED

| HORIZONTAL VESSEL DESIGN DATA | | | |
|---|---|---|---|
| CODE STAMP NO. - [illegible] - DES. & CONSTR ONLY | | | |
| OTHER SPECS.: [redacted] | | | |
| DESIGN PRESS. @ TEMP. | 2 PSI @ | 950 °F | |
| OPER. PRESS. @ TEMP. | 1 PSI @ | 650 °F | |
| STRESS RELIEVING NO | | | |
| WELD EXAMINATION NO | | | |
| JOINT EFFICIENCY | SHELL 70 % | HEADS 100 % | |
| DENSITY OF MATL = 125#/ft³ | | | |
| CORR. ALLOWANCE | SHELL — | HEADS — | |
| LINING | | | |
| MAX. ALL. PRESS. (NEW & COLD) | | | PSI |
| HYDROSTATIC TEST | | | PSI |
| HAMMER TEST | | | PSI |
| MATERIALS | SHELL | SA-240 - TP 347 | |
| | HEADS | do | |
| | SUPPORT | SA-283 Gr. "C" | |
| | INTERNALS | BOLTING - A-193 GR B8C | |
| FIREPROOFING | THK. | | SQ.FT. |
| INSULATION | 5" THK. (Thermobestos) | | SQ.FT. |
| PAINT NO | | | |
| NET FAB WEIGHT | | 3500 | LBS. |
| EMPTY WEIGHT | | | LBS. |
| OPERATING WEIGHT (Full) | | | LBS. |
| TEST WEIGHT | | | LBS. |
| MANHOLE ("HINGED OR DAVITED") | | | |
| HANDHOLE | | | |
| BY SL | DATE 9/25/7 | CHK'D | APP'D |

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| G | | | 20" | MANHOLE ([illegible]) |
| F1, F2 | | | 2" | LEVEL CONN. |
| E | | | 12" | ELECTRICAL HTR |
| D | | | 2" | TIC |
| C | | | 10" | TANK INLET |
| B | | | | PUMP |
| A | 150# | R.F. | | PUMP |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

PLATFORM WT.

LADDER CAGE WT.

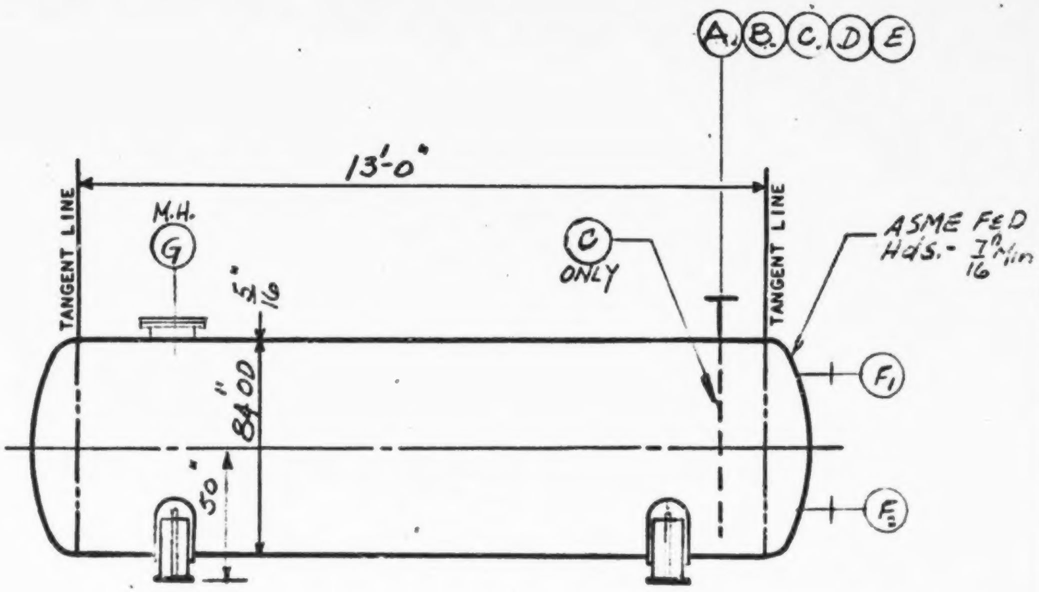
ABSORBER PUMP TANKS

V- 2A, B & C.

CONTRACT NO.

DWG. NO. PS-218-4016

7-22 SINGMASTER & BREYER



1-REQUIRED

NO. REQ'D WAS 2; "C" WAS C,E C 3"
F1 F2 WAS 1"; [illegible] NO SHELL [illegible] V3 [illegible]

## HORIZONTAL VESSEL DESIGN DATA

CODE STAMP NO - UPVC DES. & CONSTR ONLY
OTHER SPECS.: ~~SR-ST-[illegible]~~
DESIGN PRESS. @ TEMP. 2 PSI @ 950 °F
OPER. PRESS. @ TEMP. 1 PSI @ 850 °F
STRESS RELIEVING No
WELD EXAMINATION No
JOINT EFFICIENCY | SHELL 70 % | HEADS 100 %
DENSITY OF MAT'L - 125 #/ft³
CORR. ALLOWANCE | SHELL — | HEADS —
LINING —
MAX. ALL. PRESS. (NEW & COLD) — PSI
HYDROSTATIC TEST — PSI
HAMMER TEST — PSI

MATERIALS
SHELL SA-240- TP 347
HEADS do
SUPPORT SA-283 Gr. C
INTERNALS BOLTING-SA-193 Gr 38C

FIREPROOFING THK. SQ.FT.
INSULATION 5" THK. ([illegible]) SQ.FT.
PAINT No
NET FAB WEIGHT 9000 LBS.
EMPTY WEIGHT LBS.
OPERATING WEIGHT 78,000 (Full) LBS.
TEST WEIGHT 44 000 LBS.
MANHOLE ("HINGED OR")
HANDHOLE
BY BL DATE 7/5/[illegible] CHK'D APP'D

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| G | | | 20" | MANHOLE [illegible] |
| F1 F2 | 1 | l | 2-2" | LEVEL CONN |
| E | | | 12 | ELECTRICAL HTR |
| D | | | 2" | TIC |
| C | | | 10" | TANK INLET |
| B | | | 2-6" | PUMP |
| A | 150 | RF | — | PUMP |

NOZZLE SCHEDULE

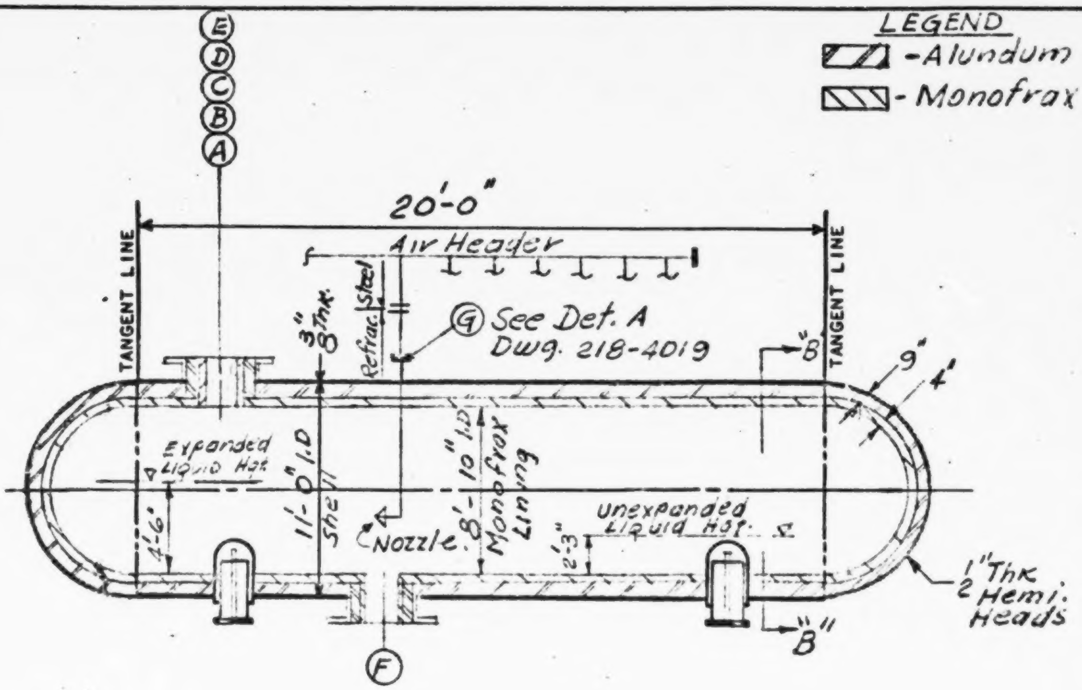
VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR
PLATFORM WT.
LADDER CAGE WT.

ABSORBER PUMP TANK

V-2D

CONTRACT NO. DWG. NO.
PS-219-0001 0A

7-23 SINGMASTER & BREYER


LEGEND
▨ -Alundum
▧ -Monofrax
20'-0"
Air Header
TANGENT LINE
TANGENT LINE
3" Thk.
8
Refrac. Steel
G See Det. A Dwg. 218-4019
"B"
"B"
9"
4"
Expanded Liquid Hgt.
4'-6"
11'-0" I.D Shell
Nozzle
8'-10" I.D Monofrax Lining
Unexpanded Liquid Hgt.
2'-3"
1 1/2" Thk. Hemi. Heads
A
B
C
D
E
F

4 REQ'D

| | | | |
|---|---|---|---|
| HORIZONTAL VESSEL DESIGN DATA | | | |
| CODE STAMP | Yes - UPVC - Latest Ed. | | |
| OTHER SPECS.: | — | | |
| DESIGN PRESS. @ TEMP. | 10 PSI @ | 800°F | |
| OPER. PRESS. @ TEMP. | 6 PSI @ | 600°F | |
| STRESS RELIEVING | NO | | |
| WELD EXAMINATION | Spot | | |
| JOINT EFFICIENCY | SHELL 85% | HEADS | 85% |
| | | | |
| CORR. ALLOWANCE | SHELL — | HEADS — | |
| LINING | As shown | | |
| MAX. ALL. PRESS. (NEW & COLD) | | | PSI |
| HYDROSTATIC TEST | | | PSI |
| HAMMER TEST | | | PSI |
| MATERIALS | SHELL | SA-204 GRA | |
| | HEADS | do | |
| | SUPPORT | SA-285 Gr C (or better) | |
| | INTERNALS | | |
| | | | |
| FIREPROOFING | — THK. | | SQ.FT. |
| INSULATION | NO THK. | | SQ.FT. |
| S.G. = 2.0 | | | |
| PAINT | | | |
| NET FAB WEIGHT | | 25,000 | LBS. |
| EMPTY WEIGHT | | 235,000 | LBS. |
| OPERATING WEIGHT | | 430,000 | LBS. |
| TEST WEIGHT | | | LBS. |
| MANHOLE ("HINGED OR DAVITED") | 2- Davited | | |
| HANDHOLE | | | |
| BY BL | DATE 11/10/7 | CHK'D | APP'D |

NOTES & REF. DWGS.

Det. for Reducers - Dwg PS-218-4019

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| H | | | 30" | M.H.- 2 Req'd |
| G | | | 3" | Air In - 10 Req'd |
| F | | | 16 | Melt Outlet( |
| E | | | 6" | Fill Line |
| D | | | 12" | Coke Inlet (Reduc |
| C | | | 24" | Oxidation Sect.-gas Out |
| B | | | 30" | Reducer Sect.-gas Outlet |
| A | | | 6" | Melt Inlet ( |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

PLATFORM WT.

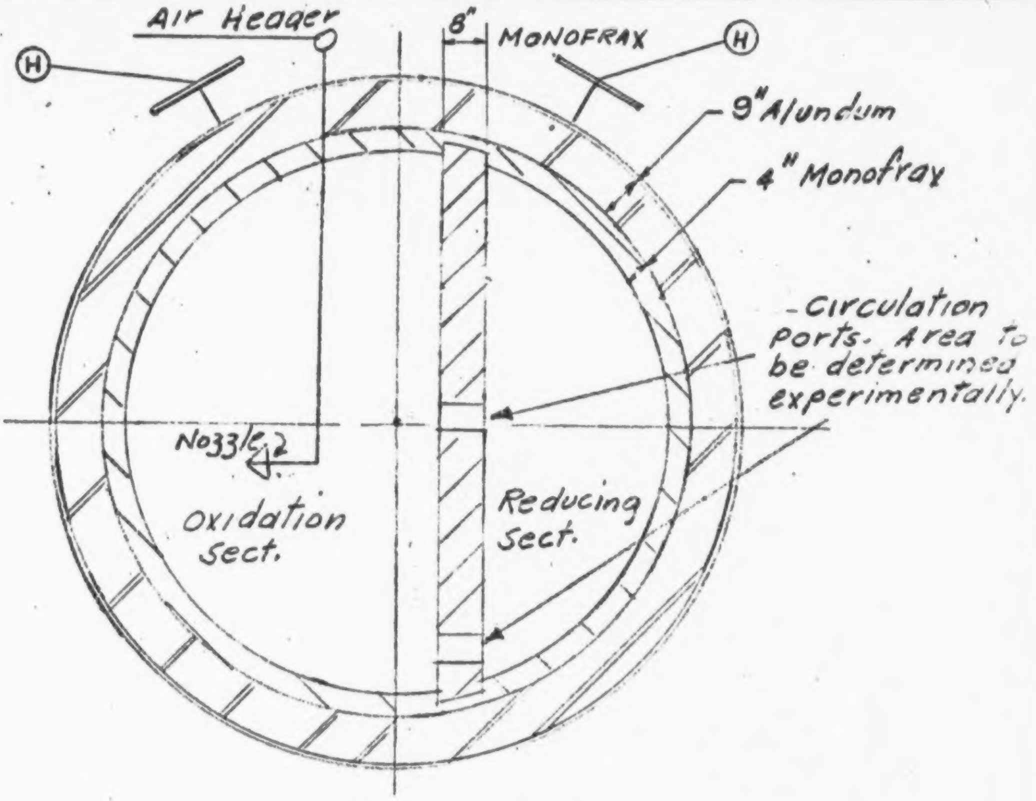
LADDER CAGE WT.

REDUCER
V-3A, B, C, & D

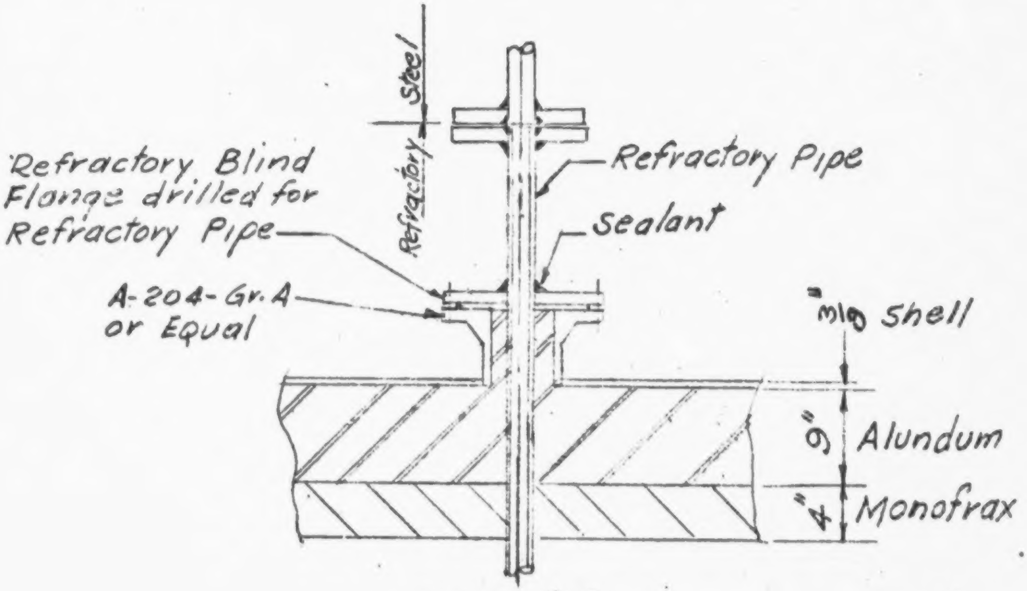
CONTRACT NO.

DWG. NO. PS-218-4019

7-24 SINGMASTER & BREYER


Air Header
8"
MONOFRAX
H
H
9" Alundum
4" Monofrax
-Circulation Ports. Area to be determined experimentally.
Nozzle 2
Oxidation Sect.
Reducing Sect.

SECTION "B-B"


Steel
Refractory
Refractory Blind Flange drilled for Refractory Pipe
A-204-Gr. A or Equal
Refractory Pipe
Sealant
3/8" Shell
9"
Alundum
4"
Monofrax

DETAIL "A"

Ref. Dwg- PS-218-4018

BY B.L.
DATE 11/3/70
CHK'D
APP'D

Details for Reducers

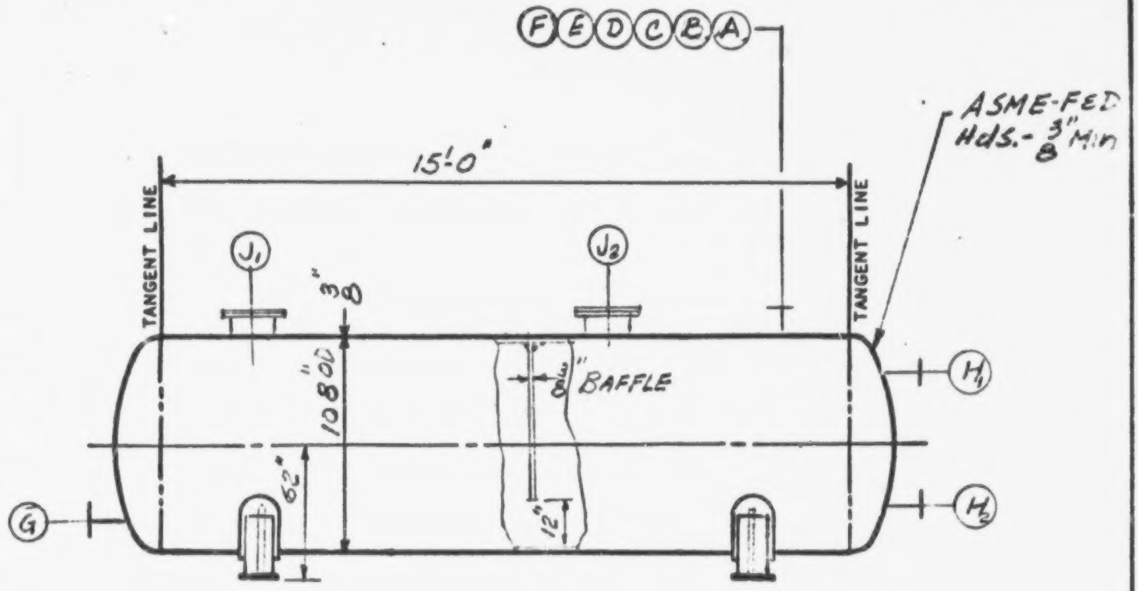
V-3 A, B, C & D

CONTRACT NO.

DWG. NO.

PS-218-4019

SINGMASTER & BREYER



2 REQUIRED

## HORIZONTAL VESSEL DESIGN DATA

| | | |
|---|---|---|
| CODE STAMP NO - UP/C DES. & CONSTR. [illegible] | | |
| OTHER SPECS.: [redacted] | | |
| DESIGN PRESS. @ TEMP. 2 PSI @ 1000 °F | | |
| OPER. PRESS. @ TEMP. 1 PSI @ 950 °F | | |
| STRESS RELIEVING NO | | |
| WELD EXAMINATION NO | | |
| JOINT EFFICIENCY | SHELL 70 % | HEADS 100 % |
| DENSITY OF MAT'L = 12.5# ft³ | | |
| CORR. ALLOWANCE | SHELL — | HEADS — |
| LINING — | | |
| MAX. ALL. PRESS. (NEW & COLD) — PSI | | |
| HYDROSTATIC TEST — PSI | | |
| HAMMER TEST — PSI | | |
| MATERIALS | SHELL SA-240 TP 347 | |
| | HEADS " " | |
| | SUPPORT [illegible] | |
| | INTERNALS SA-240 TP 347 | |
| | BOLTING SA-193 GR B8C | |
| FIREPROOFING THK. SQ.FT. | | |
| INSULATION 5" THK. THERMOBESTOS SQ.FT. | | |
| | | |
| PAINT NO | | |
| NET FAB WEIGHT 12,500 LBS. | | |
| EMPTY WEIGHT LBS. | | |
| OPERATING WEIGHT 146,000 LBS. | | |
| TEST WEIGHT 89,[illegible] LBS. | | |
| MANHOLE ("HINGED OR") | | |
| HANDHOLE | | |
| BY B.L DATE 7-30-70 | CHK'D | APP'D |

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| J1, J2 | | | 2-20" | MANHOLE [illegible] |
| H1, H2 | | | 2-2" | LEVEL CONN. |
| G | | | [illegible] | ELECTRICAL HTR. |
| F | | | [illegible] | TC |
| E | | | 2" | TRC |
| D | | | 3 | INLET (DRAW-OTHER) |
| C | | | 8 | INLET |
| B | | | | PUMP |
| A | 150 | RF | | PUMP |

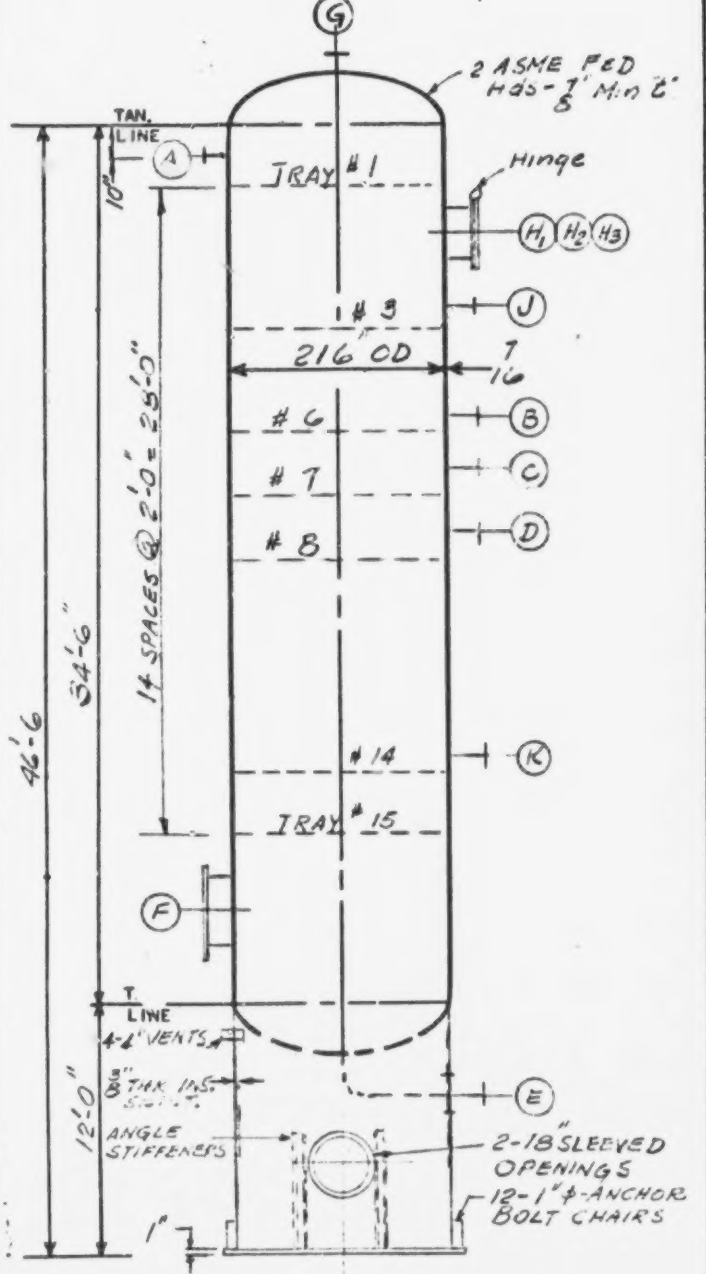
NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR
PLATFORM WT.
LADDER CAGE WT.

REDUCER QUENCH TANK
V-4A
V-4B

CONTRACT NO.
DWG. NO. PS-215-4002

7-26 SINGMASTER & BREYER


G
2 ASME F&D Hds - 7/8" Min t
TAN. LINE
A
10"
TRAY #1
Hinge
H1 H2 H3
#3
J
216" OD
7/16
#6
B
#7
C
#8
D
14 SPACES @ 2'-0" = 28'-0"
34'-6"
46'-6
#14
K
TRAY #15
F
T. LINE
4-2" VENTS
3" THK INS.
12'-0"
ANGLE STIFFENERS
E
2-18" SLEEVED OPENINGS
12-1" ϕ-ANCHOR BOLT CHAIRS
1"

11/10/75 F, E, G were 36"

Added Conn. "K"

BY P.L.
DATE 8/11/75
CHK'D
APP'D

REGENERATOR
V-5

## VERTICAL VESSEL DESIGN DATA

CODE STAMP Yes - UPVC - latest
OTHER SPECS.: [redacted]
DESIGN PRESS. @ TEMP. 1 PSI @ 1000 °F
OPER. PRESS. @ TEMP. — PSI @ 950 °F
STRESS RELIEVING —
WELD EXAMINATION SPOT
JOINT EFFICIENCY SHELL 85 % HEADS 85 %
CORR. ALLOWANCE SHELL — HEADS —
LINING —
MAX.ALL.PRESS. (NEW & COLD) — PSI
HYDROSTATIC TEST — PSI
HAMMER TEST — PSI

MATERIALS
SHELL A-240 TP 347
HEADS do
SUPPORT A-283 Gr C
INTERNALS
TRAYS - 15 SIEVE-TP 347

SP. GR = 2.0
FIREPROOFING THK. SQ.FT.
INSULATION 5" THK. SQ.FT.
INS. SUPP. RINGS Yes
PAINT No

NET FAB. WEIGHT 180,000 LBS.

FOUNDATION DATA
EMPTY WEIGHT 192,000 LBS.
OPERATING WEIGHT 386,000 LBS.
TEST WEIGHT 713,000 LBS.
WIND $M_E$ = FT. LBS.
EARTHQUAKE $M_B$ = FT. LBS.

MANHOLE (HINGED OR DAVITED)
HANDHOLE
NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| K | | | 2" | TRC |
| J | | | 4" | LIQUID IN |
| H1,2,3 | | | 24" | MANHOLES - 3 Req |
| G | | | 30" | GAS OUT |
| F | | | 30" | GAS IN |
| E | | | 2" | LIQUID OUT |
| D | | | 3" | LIQUID IN |
| C | | | 4" | LIQUID IN |
| B | | | 6" | TOTAL DRAW OUT |
| A | 150 | RF | 4" | LIQUID IN |

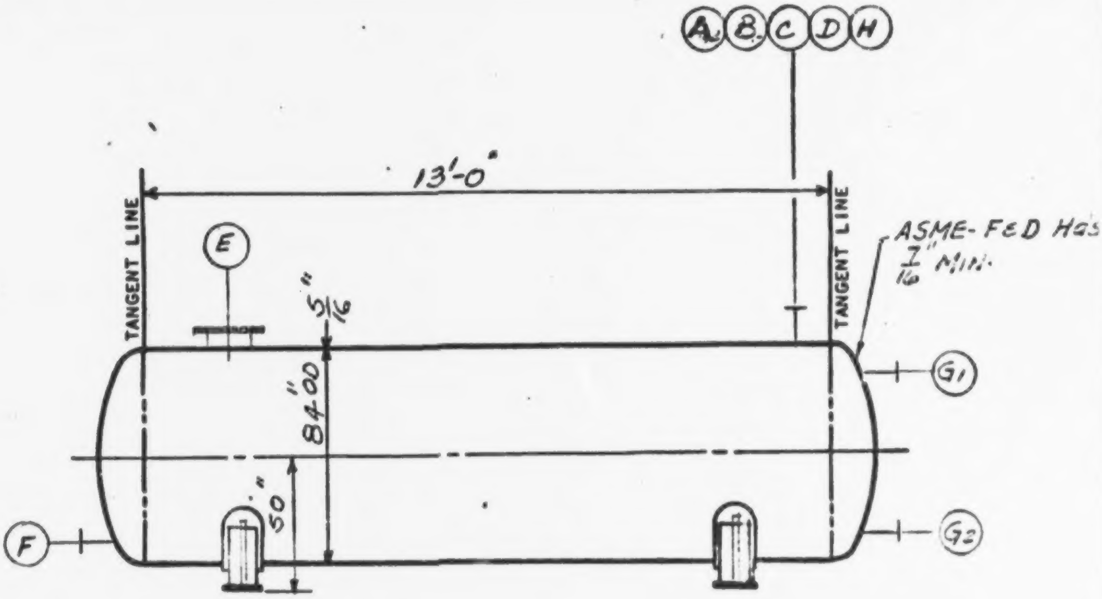
NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PLATFORMS | NO. | 3 | | | NO. PIPE SUPPORT CLIPS | TYPE I | |
| | SIZE | 45° | | | | TYPE II | |
| | WIDTH | 3'-0" | | | | TYPE III | |
| PLATFORM WEIGHT | | | | | VESSEL DAVIT | | |

LADDER Yes CAGE Yes WT.
PIPE GUIDES 3000# 1-2 CPLGS
CONTRACT NO. DWG. NO.
PS-219-4007 08

SINGMASTER & BREYER



## HORIZONTAL VESSEL DESIGN DATA

CODE STAMP N.O.-UPVC DES. & CONST. ONLY

OTHER SPECS.: [redacted]

DESIGN PRESS. @ TEMP. 2 PSI @ 1000 °F

OPER. PRESS. @ TEMP. 0 PSI @ 950 °F

STRESS RELIEVING NO

WELD EXAMINATION NO

JOINT EFFICIENCY SHELL 70% HEADS 100%

DENSITY OF MAT'L = 125#/FT³

CORR. ALLOWANCE SHELL — HEADS —

LINING —

MAX. ALL. PRESS. (NEW & COLD) — PSI

HYDROSTATIC TEST — PSI

HAMMER TEST — PSI

MATERIALS
- SHELL SA-240-TP347
- HEADS do
- SUPPORT SA-283 Gr. C
- ~~INTERNALS~~ BOLTING-SA-193 GR B8C

FIREPROOFING — THK. SQ.FT.

INSULATION 5" THK (Thermobestos) SQ.FT.

PAINT NO

NET FAB WEIGHT 9000 LBS.

EMPTY WEIGHT LBS.

OPERATING WEIGHT (Full) 73,000 LBS.

TEST WEIGHT 44,000 LBS.

MANHOLE ("HINGED OR")

HANDHOLE

BY ________ DATE ________ CHK'D ________ APP'D ________

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| H | ↑ | ↑ | 3" | DRAIN |
| G1,2 | \| | \| | 2" | LEVEL CONN. |
| F | 150 | RF | 12" | HEATER |
| E | | | 20" | MAN-HOLE (HINGED) |
| D | ↑ | ↑ | 2" | TIC |
| C | \| | \| | 6" | INLET |
| B | \| | \| | | PUMP |
| A | 150 | RF | | PUMP |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

PLATFORM WT.

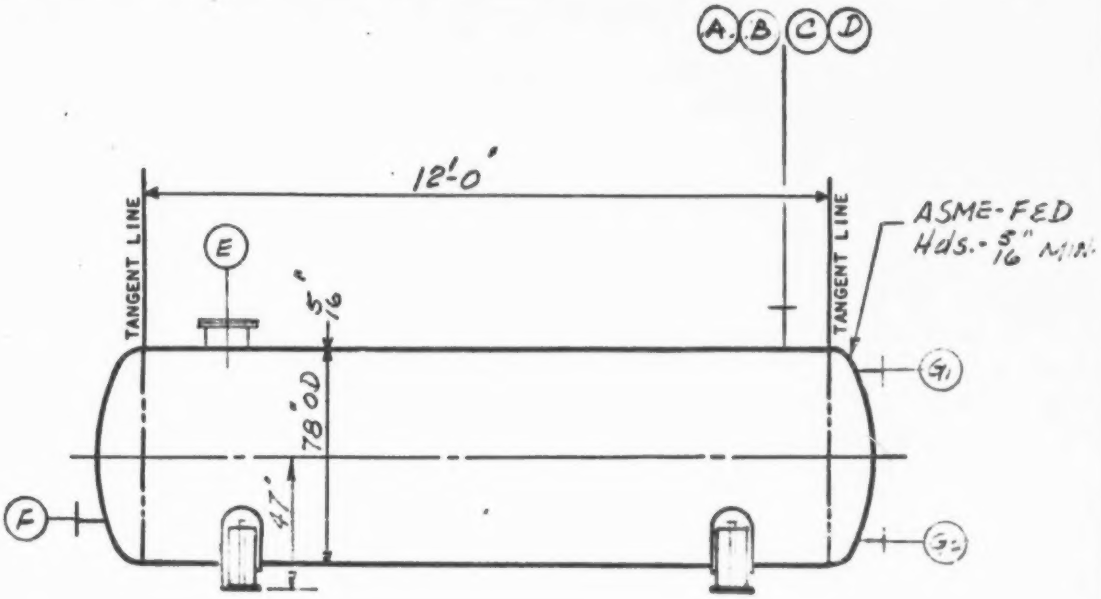
LADDER CAGE WT.

REGENERATOR BOTTOMS
PUMP TANK
V-6

CONTRACT NO.

DWG. NO.
PS-218-4003

7-28 SINGMASTER & BREYER



## HORIZONTAL VESSEL DESIGN DATA

| | | | |
|---|---|---|---|
| CODE STAMP NO-UPVC DES. & CONST. ONLY | | | |
| OTHER SPECS.: SP-ST-ET-[redacted] | | | |
| DESIGN PRESS. @ TEMP. | 2 PSI @ | 1000°F | |
| OPER. PRESS. @ TEMP. | 0 PSI @ | 950 °F | |
| STRESS RELIEVING | NO | | |
| WELD EXAMINATION | NO | | |
| JOINT EFFICIENCY | SHELL 70 % | HEADS | 100% |
| DENSITY OF MAT'L = 125 #/ft³ | | | |
| CORR. ALLOWANCE | SHELL — | HEADS — | |
| LINING — | | | |
| MAX. ALL. PRESS. (NEW & COLD) — | | | PSI |
| HYDROSTATIC TEST — | | | PSI |
| HAMMER TEST — | | | PSI |
| MATERIALS | SHELL | SA-240 TP 347 | |
| | HEADS | do | |
| | SUPPORT | SA-283 GR. C | |
| | ~~INTERNALS~~ | BOLTING - SA 193 GR B8 | |
| FIREPROOFING — | THK. | | SQ.FT. |
| INSULATION | 5" THK. (Thermobestos) | | SQ.FT. |
| PAINT — | | | |
| NET FAB WEIGHT | | 6000 | LBS. |
| EMPTY WEIGHT | | | LBS. |
| OPERATING WEIGHT | | 61,300 | LBS. |
| TEST WEIGHT | | 33,700 | LBS. |
| MANHOLE ("HINGED OR") | | | |
| HANDHOLE | | | |
| BY | DATE | CHK'D | APP'D |

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | |
|---|---|---|---|---|
| G1 G2 | ↑ | ↑ | 2" | LEVEL CONN. |
| F | 150 | RF | 12" | ELECTRICAL HTR |
| E | — | — | 20" | MANHOLE COVER |
| D | ↑ | ↑ | 2" | T/C |
| C | | | 6" | INLET |
| B | | | | PUMP |
| A | 150 | RF | | PUMP |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

PLATFORM WT.

LADDER CAGE WT.

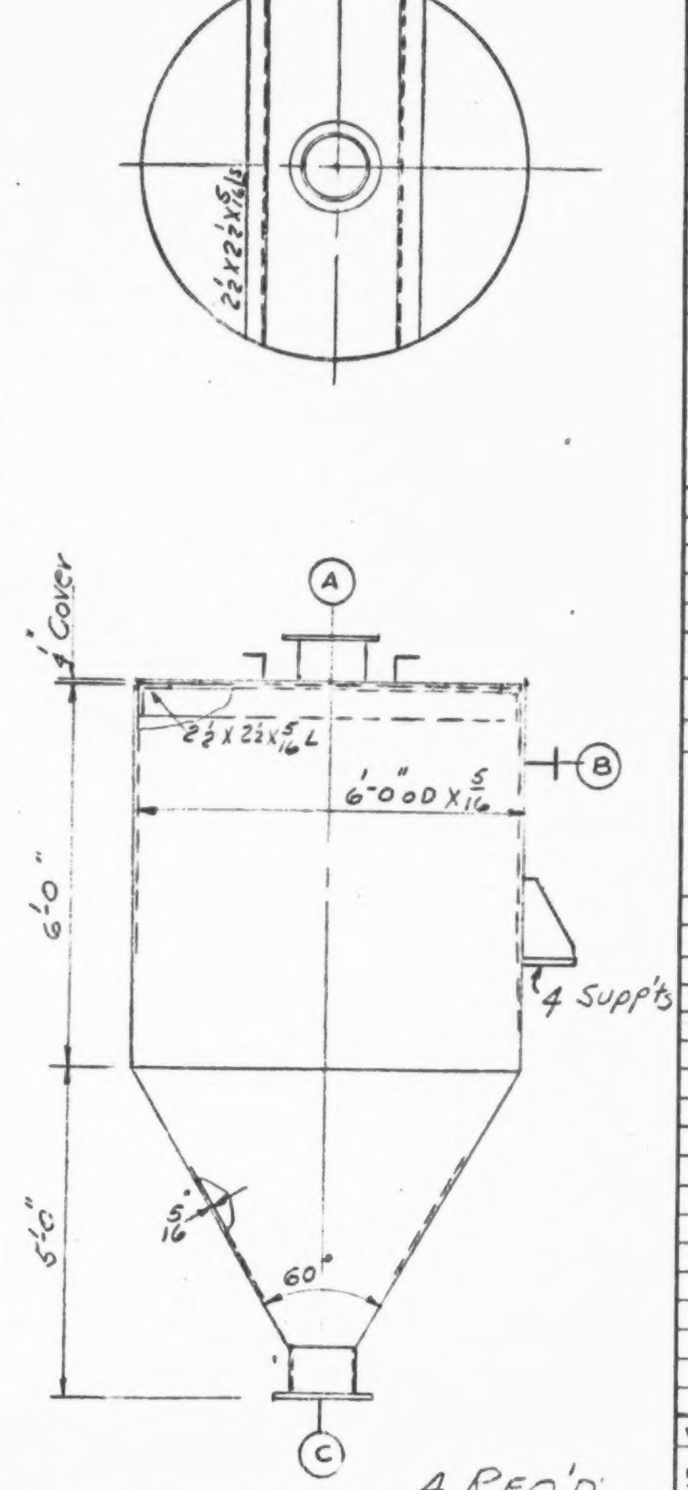
REGENERATOR INTERMEDIATE PUMP
TANK
V-7

CONTRACT NO.

DWG. NO.
PS-218-4004

7-29

SINGMASTER & BREYER



## VESSEL DESIGN DATA

| | | |
|---|---|---|
| CODE STAMP ASME Des. & Const. Only. | | |
| OTHER SPECS. | | |
| DESIGN PRESS. @ TEMP. — PSI @ — °F | | |
| OPER. PRESS. @ TEMP. PSI @ °F | | |
| STRESS RELIEVING — | | |
| WELD EXAMINATION — | | |
| JOINT EFFICIENCY | SHELL — % | HEADS — % |
| | | |
| CORR. ALLOWANCE | SHELL 1/8" | CONE 1/8" |
| LINING | | |
| MAX.ALL.PRESS. (NEW & COLD) PSI | | |
| HYDROSTATIC TEST PSI | | |
| HAMMER TEST PSI | | |

| MATERIALS | |
|---|---|
| SHELL, CONE & TOP - A-285 Gr C | |
| HEADS | |
| SUPPORT A-36 | |
| INTERNALS | |
| TRAYS | |
| | |

SP. WT = 28#/Ft³

| | | |
|---|---|---|
| FIREPROOFING | THK. | SQ.FT. |
| INSULATION | THK. | SQ.FT. |
| INS. SUPP. RINGS | | |
| PAINT Yes | | |

| | | |
|---|---|---|
| WT. OF TRAYS | FURN. BY | |
| | INST'D BY | LBS. |
| WT. & NO. OF CAPS | FURN. BY | REQ'D. |
| | INST'D BY | LBS. |
| NET FAB. WT. (LESS TRAYS AND CAPS) | 3,200 | LBS. |

| FOUNDATION DATA | | |
|---|---|---|
| EMPTY WEIGHT | 3,500 | LBS. |
| OPERATING WEIGHT | 5,500 | LBS. |
| TEST WEIGHT | — | LBS. |
| WIND | $M_B$ = | FT.LBS. |
| EARTHQUAKE | $M_B$ = | FT.LBS. |

MANHOLE ("HINGED OR DAVITED")

HANDHOLE

NOTES & REF. DWGS.:

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| C | | | 12" | Outlet |
| B | | | 2" | Level Control |
| A | | | 12" | Inlet |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PLAT-FORMS | NO. | | | | NO. PIPE SUPPORT CLIPS | TYPE I | |
| | SIZE | | | | | TYPE II | |
| | WIDTH | | | | | TYPE III | |
| PLATFORM WEIGHT | | | | | VESSEL DAVIT | | |

LADDER CAGE WT.

PIPE GUIDES 3000# 1/2 CPLGS.

CONTRACT NO.

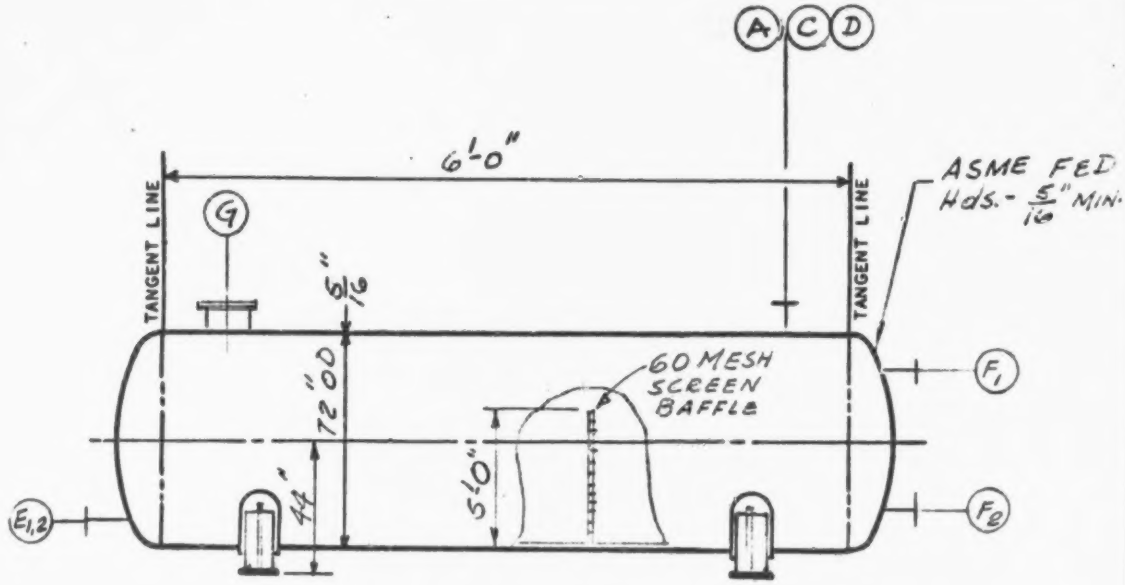
DWG. NO. PS-316-1017

4 REQ'D

BY B.L.
DATE 11/5/70
CHK'D
APP'D

COKE BINS
V-8A, B, C, & D

SINGMASTER & BREYER



## HORIZONTAL VESSEL DESIGN DATA

CODE STAMP NO-UPVC DES. & CONSTR. ONLY

OTHER SPECS.: SP [redacted]

DESIGN PRESS. @ TEMP. 0 PSI @ 850 °F

OPER. PRESS. @ TEMP. 0 PSI @ 800 °F

STRESS RELIEVING NO

WELD EXAMINATION [illegible]

JOINT EFFICIENCY SHELL 70% HEADS 100%

DENSITY OF MATL - 125#/FT³

CORR. ALLOWANCE SHELL — HEADS —

LINING

MAX. ALL. PRESS. (NEW & COLD) — PSI

HYDROSTATIC TEST — PSI

HAMMER TEST — PSI

MATERIALS

SHELL SA-240 TP347

HEADS S/S

SUPPORT SA-285 GR. C

INTERNALS 347 S.S.

BOLTING SA-193 Gr. B8C

FIREPROOFING THK. SQ.FT.

INSULATION 5" THK (Thermobestos) SQ.FT.

PAINT —

NET FAB WEIGHT 5,500 LBS.

EMPTY WEIGHT LBS.

OPERATING WEIGHT (FULL) 52,400 LBS.

TEST WEIGHT 29,000 LBS.

MANHOLE ("HINGED OR ~~DAVITED~~")

HANDHOLE

BY DATE CHK'D APP'D

NOTES & REF. DWGS.

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| G | | | 20" | MANHOLE API 650 DES. |
| F | | | 6 | LEVEL CONN |
| E, E2 | | | 14 | ELECTRICAL ATT. |
| D | | | [illegible] | TIC |
| C | | | 12 | SOLIDS IN |
| A | 150 | R.F | | PUMP |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

PLATFORM WT.

LADDER CAGE WT.

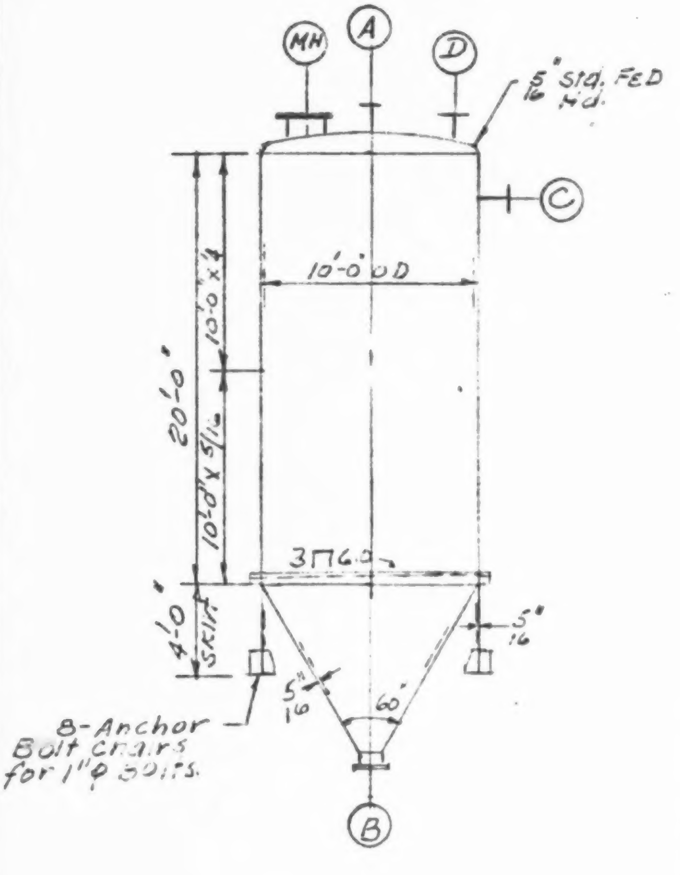
$M_2CO_3$ MELT TANK
V-9

CONTRACT NO.

DWG. NO. PS-215-4005

7-31

SINGMASTER & BREYER



3 Req'd

## VESSEL DESIGN DATA

CODE STAMP - NO- [illegible] Des, [illegible]
OTHER SPECS.: [redacted]
DESIGN PRESS. @ TEMP. PSI @ °F
OPER. PRESS. @ TEMP. 0 PSI @ Amb. °F
STRESS RELIEVING —
WELD EXAMINATION —
JOINT EFFICIENCY SHELL [illegible] % HEADS [illegible] %
CORR. ALLOWANCE SHELL — HEADS —
LINING
MAX.ALL.PRESS.(NEW & COLD) PSI
HYDROSTATIC TEST PSI
HAMMER TEST PSI

| MATERIALS | |
|---|---|
| SHELL - | A-285 Gr. C |
| HEADS | do |
| SUPPORT | do |
| INTERNALS | |
| TRAYS | |

SP.GR. = 1.04
FIREPROOFING — THK. SQ.FT.
INSULATION — THK. SQ.FT.
INS. SUPP. RINGS —
PAINT-

| | | |
|---|---|---|
| WT. OF TRAYS | FURN. BY | |
| | INST'D BY | LBS. |
| WT. & NO. OF CAPS | FURN. BY | REQ'D. |
| | INST'D BY | LBS. |

NET FAB.WT. (LESS TRAYS AND CAPS) LBS.

| FOUNDATION DATA | | |
|---|---|---|
| EMPTY WEIGHT | 15,000 | LBS. |
| OPERATING WEIGHT | (Full) [illegible] | LBS. |
| TEST WEIGHT | | LBS. |
| WIND | $M_B$ = | FT.LBS. |
| EARTHQUAKE | $M_B$ = | FT.LBS. |

MANHOLE (HINGED OR DAVITED)
HANDHOLE
NOTES & REF.DWGS.:

| MK. | RTG. | FCG. | SIZE | REMARKS |
|---|---|---|---|---|
| MH | | | 20 | Manhole [illegible] |
| | | | | |
| | | | | |
| | | | | |
| D | | | 8" | Dust Collector |
| C | | | 4" | Level |
| B | | | | Solids Out |
| A | 150# | RF | 12" | Solids In |

NOZZLE SCHEDULE

VESSEL FABRICATOR TO SUPPLY CLIPS ONLY FOR

| PLATFORMS | | | | NO. PIPE SUPPORT CLIPS | |
|---|---|---|---|---|---|
| NO. | | | | TYPE I | |
| SIZE | | | | TYPE II | |
| WIDTH | | | | TYPE III | |
| PLATFORM WEIGHT | | | | VESSEL DAVIT | |

LADDER CAGE WT.
PIPE GUIDES 3000# 1/2 CPLGS.

BY R.L.
DATE 5/3/70
CHK'D
APP'D

Silos
T-3
T-4
T-5

CONTRACT NO.
DWG. NO. PS-[illegible]-4006

SINGMASTER & BREYER

d. Motor List

The list of motors for all required equipment are contained in the following pages. This list was used to estimate the electrical construction cost.

| EQUIP. NO. | SERVICE | HORSE POWER |  | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA |  | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | OPER. | SPARE |  |  |  |  |  | EST. | FIRM |  |
| B-2 | Filter Displacement Blower | 10 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| F-1A&1B | Fly Ash Filter-Drive | 2 | 2 |  | 480 |  |  |  | X |  |  |
|  | -Screw | 5 | 5 |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| P-1A; 1A(S) | Absorber Pumps | 125 | 125 |  | 480 |  |  |  | X |  |  |
| P-1B; 1B(S) |  | 125 | 125 |  | 480 |  |  |  | X |  |  |
| P-1C; 1C(S) |  | 125 | 125 |  | 480 |  |  |  | X |  |  |
| P-1D; 1D(S) |  | 125 | 125 |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| V-1A | Absorber Bypass Valve 3@ | 3 |  |  | 480 |  |  |  | X |  |  |
| V-1B | 3@ | 3 |  |  | 480 |  |  |  | X |  |  |
| V-1C | 3@ | 3 |  |  | 480 |  |  |  | X |  |  |
| V-1D | 3@ | 3 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| V-2A | Absorber Pump Tank-Elec.Htr. | 30KW |  |  | 480 |  |  |  | X |  |  |
| V-2B |  | 30KW |  |  | 480 |  |  |  | X |  |  |
| V-2C |  | 30KW |  |  | 480 |  |  |  | X |  |  |
| V-2D |  | 30KW |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |

**MOTOR ENCLOSURE**

O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL - SEE REMARKS

***MOTOR TYPE** - SQ. CAGE IND. UNLESS OTHERWISE NOTED

SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED - CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED - CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED - VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

| SINGMASTER & BREYER | NEW YORK, N.Y. |
|---|---|
| PREPARED BY S.F. | MOTOR LIST |
| DATE 11-20-70 | A.I. Process<br>Absorber Area |
| SH. 1 OF | JOB NO. PS-218 REV. |

FORM E-478

| EQUIP. NO. | S E R V I C E | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | R E M A R K S* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| B-1A | Combustion Air Blower | 300 | | | 2400 | | | | X | | |
| B-1B | | 300 | | | 2400 | | | | X | | |
| B-1C | | 300 | | | 2400 | | | | X | | |
| B-1D | | 300 | | | 2400 | | | | X | | |
| | | | | | | | | | | | |
| E-1A | Reducer Product Cooler 2 @ | 10 | | | 480 | | | | X | | |
| E-1B | 2 @ | 10 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| F-2A&B | Coke Filter - Drive | 2 | 2 | | 480 | | | | X | | |
| | - Screw | 5 | 5 | | 480 | | | | X | | |
| | | | | | | | | | | | |
| P-2A; 2A(S) | Reducer Pumps | 150 | 150 | | 480 | | | | X | | |
| P-2B; 2B(S) | | 150 | 150 | | 480 | | | | X | | |
| | | | | | | | | | | | |
| V-4A | Reducer Quench Tank-Elec.Htr. | 30 | KW | | 480 | | | | X | | |
| V-4B | | 30 | KW | | 480 | | | | X | | |
| | | | | | | | | | | | |
| W-1A | Weigh Belt Feeder | 2 | | | 480 | | | | X | | |
| W-1B | | 2 | | | 480 | | | | X | | |
| W-1C | | 2 | | | 480 | | | | X | | |
| W-1D | | 2 | | | 480 | | | | X | | |

**MOTOR ENCLOSURE**

O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL - SEE REMARKS

***MOTOR TYPE - SQ. CAGE IND. UNLESS OTHERWISE NOTED**

SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED - CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED - CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED - VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

SINGMASTER & BREYER NEW YORK, N.Y.

PREPARED BY S.F.

DATE 11-20-70

SH. 2 OF

MOTOR LIST

A.I. Process
Reducer Area

JOB NO. PS-218

REV.

FORM E-478

| EQUIP. NO. | SERVICE | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| E-4 | Regen. Bottoms Cooler 2@ | 5 | | | 480 | | | | X | | |
| E-5 | Regen. Intermediate Cooler 2@ | 7½ | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| P-3;3(S) | Regenerator Btms Pump | 75 | 75 | | 480 | | | | X | | |
| P-4;4(S) | Regenerator Intermediate Pump | 60 | 60 | | 480 | | | | X | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| V-6 | Regen. Btms Pump Tank-Elec.Htr.30KW | | | | 480 | | | | X | | |
| V-7 | Regen. Int. Pump Tank-Elec.Htr.30KW | | | | 480 | | | | X | | |

**MOTOR ENCLOSURE**

O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL – SEE REMARKS

***MOTOR TYPE** – SQ. CAGE IND. UNLESS OTHERWISE NOTED

SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED – CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED – CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED – VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

| SINGMASTER & BREYER | NEW YORK, N.Y. |
|---|---|
| PREPARED BY S.F. | MOTOR LIST |
| DATE 11-20-70 | A.I. Process<br>Regenerator Area |
| SH. 3 OF | JOB NO. PS-218 REV. |

| EQUIP. NO. | SERVICE | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| C-1 | Crusher - Drive "A" | 100 | | | 480 | | | | X | | |
| C-1 | Crusher - Drive "B" | 125 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| G-1 | Transfer Conveyor & Feeder | 1 | | | 480 | | | | X | | |
| G-1 | Transfer Conveyor & Feeder | 1 | | | 480 | | | | X | | |
| G-2 | Bucket Elevator | 3 | | | 480 | | | | X | | |
| G-3 | Bucket Elevator | 5 | | | 480 | | | | X | | |
| G-4 | Reversing Belt Conveyor | 3 | | | 480 | | | | X | | |
| G-5 | Coke Belt Conveyor w/Tripper | 5 | | | 480 | | | | X | | |
| G-5A | Elevating Belt Conveyor | 5 | | | 480 | | | | X | | |
| G-6 | Dust Collector | 5 | | | 480 | | | | X | | |
| G-7 | Coke Silo Dust Collector | 2 | | | 480 | | | | X | | |
| G-8 | Coke Silo Dust Collector | 2 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| S-1 | Coke Screen | 7½ | | | 480 | | | | X | | |

MOTOR ENCLOSURE

O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL - SEE REMARKS

*MOTOR TYPE – SQ. CAGE IND. UNLESS OTHERWISE NOTED

SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED – CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED – CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED – VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

**SINGMASTER & BREYER** NEW YORK, N.Y.

PREPARED BY S.F.

DATE 11-20-70

SH. 4 OF

MOTOR LIST

A.I. Process
Coke Handling

JOB NO. PS-218

REV.

FORM E-470

| EQUIP. NO. | SERVICE | HORSE POWER |  | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA |  | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | OPER. | SPARE |  |  |  |  |  | EST. | FIRM |  |
| G-9 | $M_2CO_3$ Bucket Elevator | 5 |  |  | 480 |  |  |  | X |  |  |
| G-10 | $M_2CO_3$ Conveyor | 2 |  |  | 480 |  |  |  | X |  |  |
| G-11 | $M_2CO_3$ Silo Feed Conveyor | 3 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| W-2 | Weigh Feeder | 1 |  |  | 480 |  |  |  | X |  |  |
| W-3 | Weigh Feeder | 1 |  |  | 480 |  |  |  | X |  |  |
| W-3 | Weigh Feeder | 1 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| V-9 | $M_2CO_3$ Melt Tank Elect. Htr. | 2-125KW each |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| T-2 | Silo Dust Collector | 2 |  |  | 480 |  |  |  | X |  |  |
| T-3 | Silo Dust Collector | 2 |  |  | 480 |  |  |  | X |  |  |
| T-4 | Silo Dust Collector | 2 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| P-5 | $M_2CO_3$ Makeup Pump | 5 |  |  | 480 |  |  |  | X |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
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MOTOR ENCLOSURE
O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPEC - SPECIAL - SEE REMARKS

*MOTOR TYPE – SQ. CAGE IND. UNLESS OTHERWISE NOTED
SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED – CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED – CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED – VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

SINGMASTER & BREYER NEW YORK, N.Y.
PREPARED BY S.F.
MOTOR LIST
DATE 11-20-70
A.I. Process
$M_2CO_3$ Makeup Area
SH. 5 OF
JOB NO. PS-218
REV.

FORM E-478

| EQUIP. NO. | SERVICE | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| X-2 | Instrument Air Compressor | 50 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| X-3 | Instrument Air Dryer | 10KW | | | 480 | | | | X | | |
| | | | | | | | | | | | |
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**MOTOR ENCLOSURE**

O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL - SEE REMARKS

*MOTOR TYPE – SQ. CAGE IND. UNLESS OTHERWISE NOTED
SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED – CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED – CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED – VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

SINGMASTER & BREYER NEW YORK, N.Y.

PREPARED BY S.F.
DATE 11-20-70
SH. 6 OF

MOTOR LIST

A.I. Process
Utility Area

JOB NO. PS-218
REV.

FORM E-478

| EQUIP. NO. | SERVICE | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| A-101 | Dissolving Sump Agitator | 5 | | | | | | | X | | |
| A-102 | Fly Ash-Coke Slurry Tank Agit. | 3 | | | | | | | X | | |
| A-103 | $LiHCO_3$ Reactor Agitator | 5 | | | | | | | X | | |
| A-104 | $Li_2CO_3$-Fly Ash Filter Cake | | | | | | | | X | | |
| | Receiver Agitator | 5 | | | | | | | | | |
| A-105 | $LiHCO_3$ Reactor Prod.Surge Rec. | 5 | | | | | | | X | | |
| A-106 | $Li_2CO_3$ Reactor Product Surge | 5 | | | | | | | X | | |
| | | | | | | | | | | | |
| B-101 | Exhaust Fan | 5 | | | 480 | | | | X | | |
| B-102 | Hot Air Blower | 25 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| D-101 | $Li_2CO_3$ Dryer Drive | 7½ | | | 480 | | | | X | | |
| D-101 | $Li_2CO_3$ Dryer I.D. Fan | 5 | | | 480 | | | | X | | |
| D-101 | $Li_2CO_3$ Dryer Feeder | 2 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| F-101 | $Li_2CO_3$-Fly Ash Filter-Agit. | 1 | | | 480 | | | | X | | |
| | -Drive | 1 | | | 480 | | | | X | | |
| | -Vac.Pump | 50 | | | 480 | | | | X | | |
| | -Filtrate Pump (P-102) | 2 | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

MOTOR ENCLOSURE
O - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL - SEE REMARKS

*MOTOR TYPE - SQ. CAGE IND. UNLESS OTHERWISE NOTED
SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED - CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED - CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED - VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

SINGMASTER & BREYER NEW YORK, N.Y.

PREPARED BY S.F.

DATE 11-20-70

SH. 7 OF

MOTOR LIST

A.I. Process
$Li_2CO_3$ Recovery Area

JOB NO. PS-218

REV.

FORM E-478

| EQUIP. NO. | SERVICE | HORSE POWER | | SYN. R.P.M. | VOLTAGE | NO. OF PHASES | MOTOR ENCL. | F.L. CURR. | DATA | | REMARKS* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OPER. | SPARE | | | | | | EST. | FIRM | |
| F-102 | Fly Ash Filter - Drive | 1 | | | 480 | | | | X | | |
| | - Agitator | 1 | | | 480 | | | | X | | |
| | - Vacuum Pump | 50 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| F-103 | $Li_2CO_3$ Filter - Agitator | ½ | | | 480 | | | | X | | |
| | - Drive | ½ | | | 480 | | | | X | | |
| | - Vacuum Pump | 20 | | | 480 | | | | X | | |
| | - Filtrate Pump (P-107) | 1½ | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| G-101 | Dried $Li_2CO_3$ Conveyor | 2 | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| P-101,101(S) | $Li_2CO_3$-Fly Ash Fil.Feed Pump | 1½ | 1½ | | 480 | | | | X | | |
| P-102 | See F-101 | | | | 480 | | | | X | | |
| P-103,103(S) | Slurry Disposal Pump | 1 | 1 | | 480 | | | | X | | |
| P-104,104(S) | Fly Ash Filter Feed Pump | 1 | 1 | | 480 | | | | X | | |
| P-105 | $Li_2CO_3$ React.Prod.Pump | 1½ | | | 480 | | | | X | | |
| P-106 | $Li_2CO_3$ Filter Feed Pump | 1 | | | 480 | | | | X | | |
| P-107 | See F-103 | | | | 480 | | | | X | | |
| | | | | | | | | | | | |
| X-101 | $CO_2$ Generator-Blower | 30 | | | 480 | | | | X | | |
| | -Compressor | 200 | | | 480 | | | | X | | |

**MOTOR ENCLOSURE**
G - OPEN DRIP-PROOF
OE - OPEN, ENCAPSULATED
TENV - TOTALLY ENCLOSED NON-VENTILATED
TEFC - TOTALLY ENCLOSED FAN COOLED
EP - EXPLOSION PROOF
SP - SPLASH PROOF
SPLE - SPECIAL – SEE REMARKS

***MOTOR TYPE – SQ. CAGE IND. UNLESS OTHERWISE NOTED**
SYN - SYNCHRONOUS
WR - WOUND ROTOR
CP1 - CONSEQUENT POLE 2 SPEED – CONSTANT HP
CP2 - CONSEQUENT POLE 2 SPEED – CONSTANT TORQUE
CP3 - CONSEQUENT POLE 2 SPEED – VARIABLE TORQUE
MW - MULTI-WINDING
OTHER - SPECIFY AS REQUIRED

| SINGMASTER & BREYER | NEW YORK, N.Y. |
|---|---|
| PREPARED BY<br>S.F. | MOTOR LIST |
| DATE<br>11-20-70 | A.I. Process<br>$Li_2CO_3$ Recovery Area |
| SH. 8 OF | JOB NO. PS-218 REV. |

FORM E-478

## 8. PLANT ARRANGEMENT DRAWINGS - BASE CASE

The conceptual arrangement of equipment required to accomplish the removal of $SO_x$ from the base case power plant flue gases and to recover $Li_2CO_3$ from the discarded filter cakes is shown on the attached drawings:

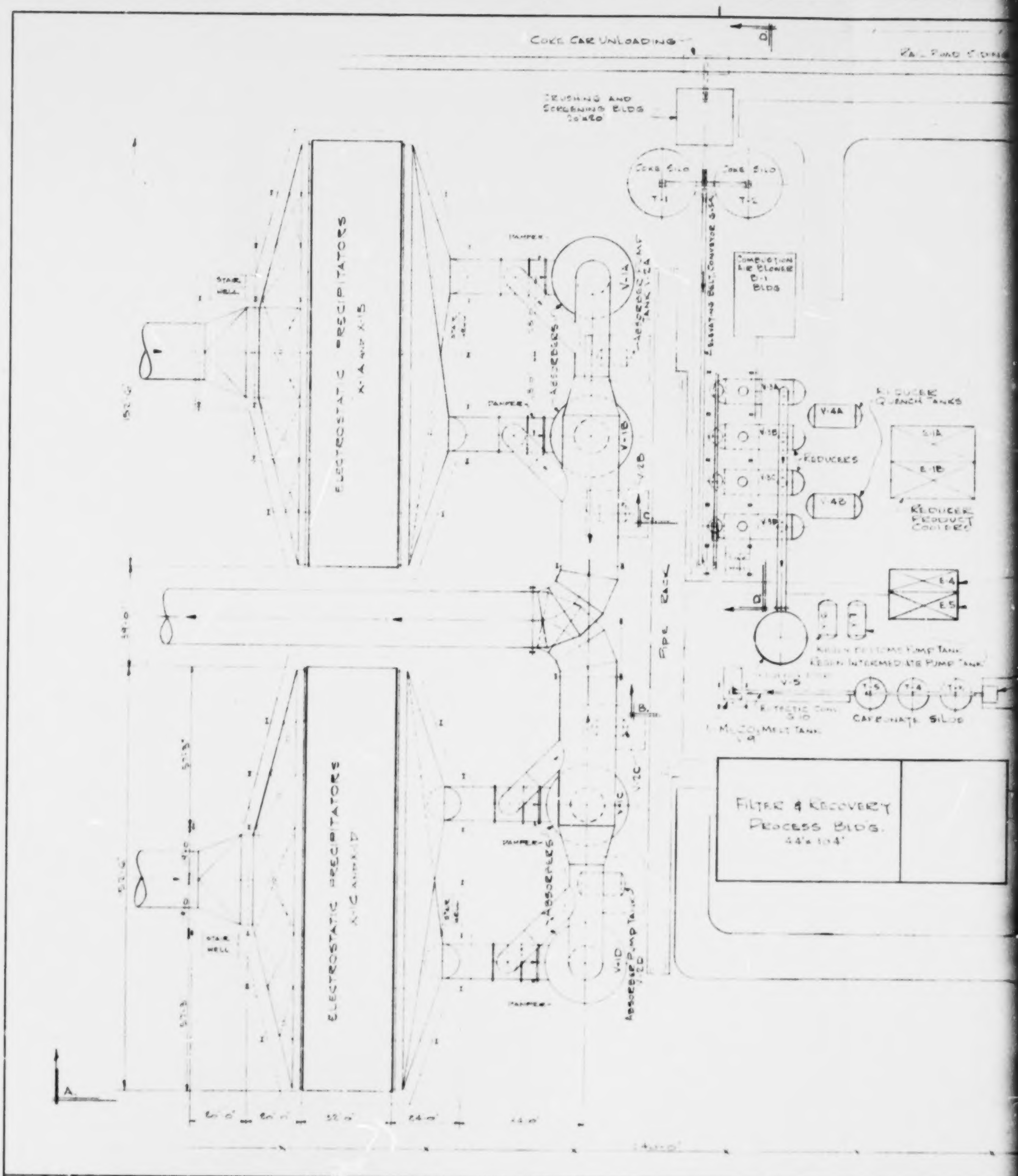
PS-218-0501 - Site Arrangement - Plans

PS-218-0502 - Site Arrangement - Elevation, Sections

PS-218-0503 - Filter & Recovery Process Bldg. - Equipment Arrangement

It was assumed that makeup carbonate salts would be shipped to the plant by truck and that coke would be delivered by rail cars.

Changehouse facilities for plant operating personnel were presumed to be available at the power plant.


COKE CAR UNLOADING
RAIL ROAD SIDING
CRUSHING AND SCREENING BLDG 20'x20
COKE SILO T-1
COKE SILO T-2
ELEVATING BELT CONVEYOR
COMBUSTION AIR BLOWER B-1 BLDG
DAMPER
STAIR WELL
ELECTROSTATIC PRECIPITATORS X-1A AND X-1B
ABSORBERS
V-1A
V-1B
V-2B
ABSORBER PUMP TANK V-2A
REDUCER QUENCH TANKS
V-3A
V-3B
V-3C
V-3D
V-4A
V-4B
REDUCERS
E-1A
E-1B
REDUCER PRODUCT COOLERS
E-4
E-5
RESIN BOTTOMS PUMP TANK
RESIN INTERMEDIATE PUMP TANK
V-5
EUTECTIC CONV. S-10
CARBONATE SILOS
T-5
T-4
MeCO3 MELT TANK V-9
PIPE RACK
FILTER & RECOVERY PROCESS BLDG. 44'x104'
ELECTROSTATIC PRECIPITATORS X-1C AND X-1D
ABSORBERS
V-1C
V-2C
V-1D
ABSORBER PUMP TANK V-2D
A
B
C
D
52'0"
52'0"
52'0"
20'0"
20'0"
32'0"
24'0"
140'0"
19
18
17
16
15
14
13
12
11
10
9

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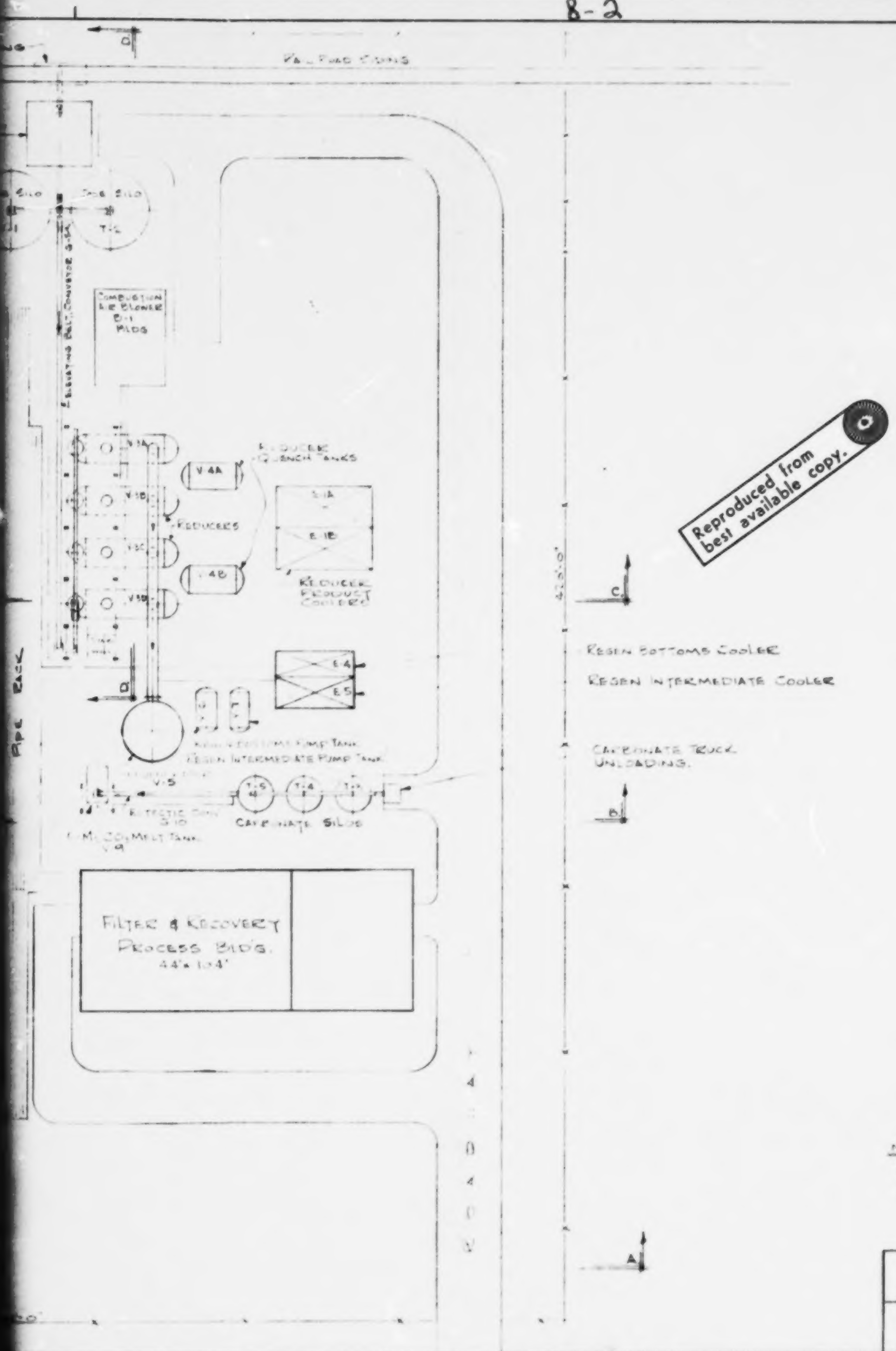
RAIL ROAD SIDING
SILO
COKE SILO
T-2
ELEVATING BELT CONVEYOR
COMBUSTION AIR BLOWER B-1 BLDG
REDUCER QUENCH TANKS
V-4A
V-4B
V-3A
V-3B
V-3C
V-3D
REDUCERS
E-1A
E-1B
REDUCER PRODUCT COOLERS
E-4
E-5
REGEN BOTTOMS PUMP TANK
REGEN INTERMEDIATE PUMP TANK
V-5
EUTECTIC BIN
CARBONATE SILOS
T-5
T-4
T-3
M. CO3 MELT TANK V-9
FILTER & RECOVERY PROCESS BLD'G. 44'x104'
PIPE RACK
425'-0"
REGEN BOTTOMS COOLER
REGEN INTERMEDIATE COOLER
CARBONATE TRUCK UNLOADING
A
B
C
D

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PS218-0501 | 0

NOTE:—
PLOT PLAN BASED ON 800 MW POWER PLANT USING COAL WITH SULFUR CONTENT OF 3%.

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

ATOMICS INTERNATIONAL MOLTEN CARBONATE PROCESS

CONCEPTIONAL SITE ARRANGEMENT PLAN

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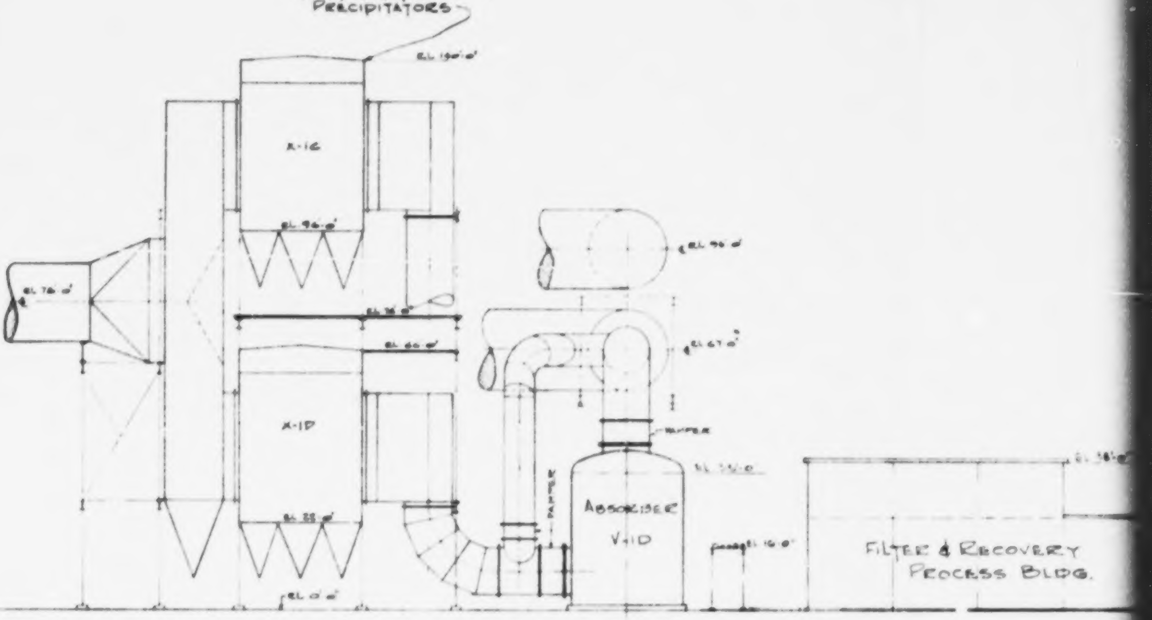
NEW YORK N.Y. 10017

| | | | | |
|---|---|---|---|---|
| DR BY D.Ve... | S & B APPROVAL | DATE 7-1-70 | DWG NO. PS218-0501 | REV 0 |
| CH BY | CLIENT APPROVAL | DATE | | |
| SCALE 1/16"=1'-0" | | | | |

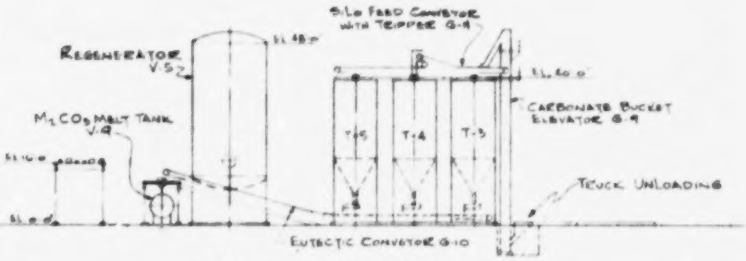
B

A

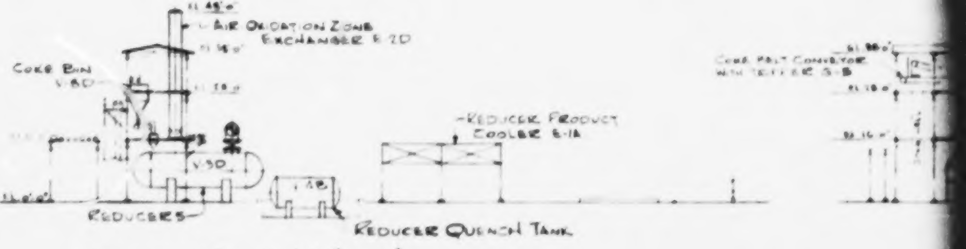

ELECTROSTATIC PRECIPITATORS
EL 190'-0"
X-1C
EL 96'-0"
EL 78'-0"
EL 76'-0"
EL 60'-0"
X-1D
EL 22'-0"
EL 0'-0"
EL 90'-0"
EL 67'-0"
DAMPER
DAMPER
EL 35'-0"
ABSORBER V-1D
EL 16'-0"
FILTER & RECOVERY PROCESS BLDG.
EL 38'-0"

SECTION "A-A"

SCALE 1/16"=1'-0"


SILO FEED CONVEYOR WITH TRIPPER G-9
REGENERATOR V-5
EL 48'-0"
EL 60'-0"
$M_2CO_3$ MELT TANK V-9
CARBONATE BUCKET ELEVATOR G-9
T-5
T-4
T-3
EL 16'-0"
TRUCK UNLOADING
EL 0'-0"
EUTECTIC CONVEYOR G-10

SECTION "B-B"


EL 45'-0"
AIR OXIDATION ZONE EXCHANGER E-2D
EL 38'-0"
COKE BIN V-8D
EL 28'-0"
COKE BELT CONVEYOR WITH TRIPPER G-8
EL 38'-0"
EL 28'-0"
-REDUCER PRODUCT COOLER E-1A
EL 16'-0"
V-3D
EL 0'-0"
REDUCERS
REDUCER QUENCH TANK

SECTION "C-C"

| MK. | DATE | REVISIONS | DR. CH. | APP. | MK. | DATE | REVISIONS | DR. CH. | APP. | NUMBER | REFERENCE DRAWINGS |
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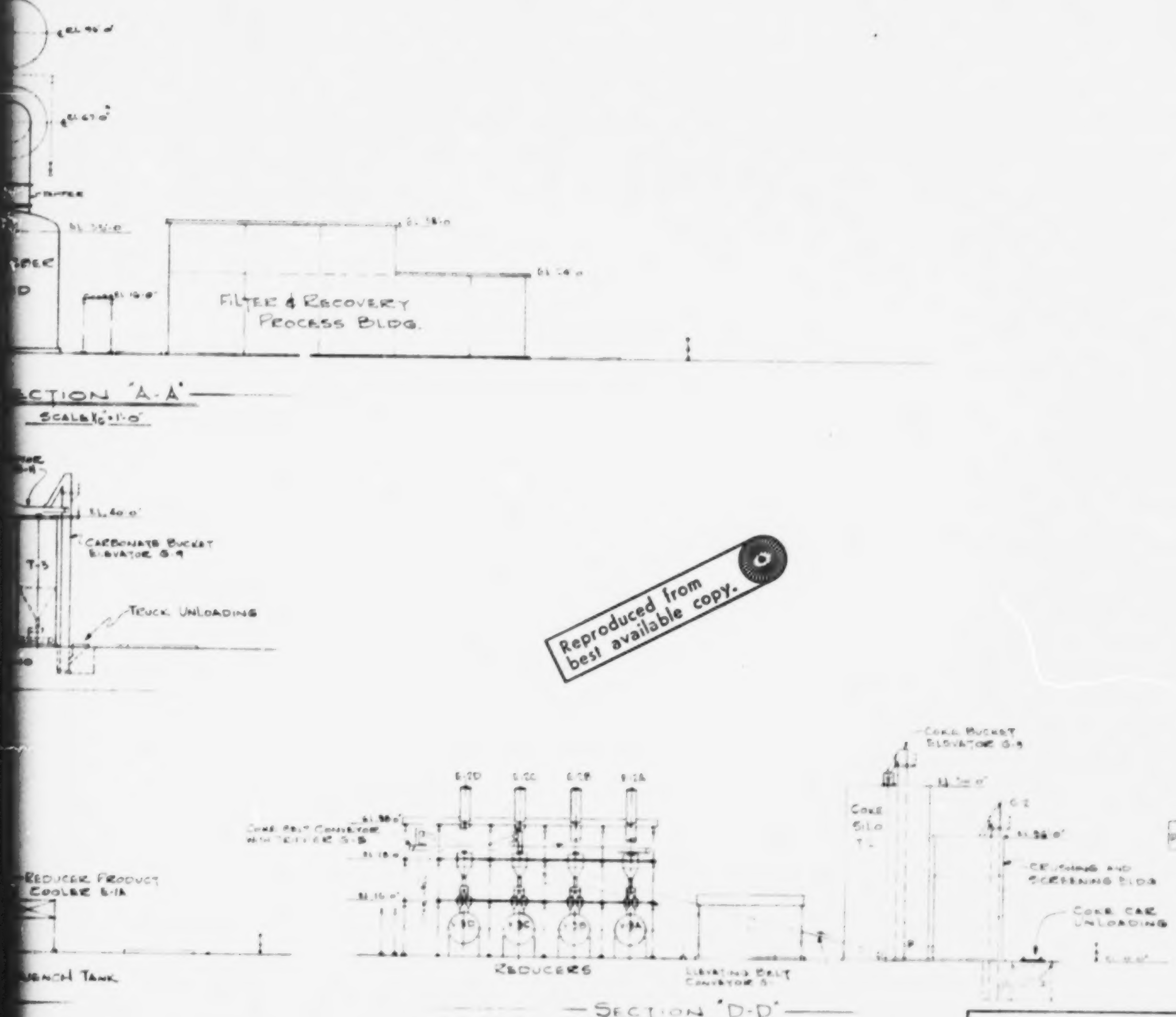
19 18 17 16 15 14 13 12 11 10 9

B



EL 90'-0"
EL 67'-0"
STRIPPER
EL 55'-0"
SPEE
D
EL 18'-0"
EL 38'-0"
EL 24'-0"
FILTER & RECOVERY
PROCESS BLDG.
SECTION 'A-A'
SCALE 3/16"=1'-0"
EL 40'-0"
CARBONATE BUCKET ELEVATOR G-9
T-3
TRUCK UNLOADING
REDUCER PRODUCT COOLER E-1A
QUENCH TANK
G-2D
G-2C
G-2B
G-2A
EL 38'-0"
COKE BELT CONVEYOR WITH TRIPPER G-5
EL 18'-0"
EL 16'-0"
REDUCERS
ELEVATING BELT CONVEYOR G-
COKE BUCKET ELEVATOR G-9
EL 70'-0"
COKE SILO T-
G-2
EL 38'-0"
CRUSHING AND SCREENING BLDG.
COKE CAR UNLOADING
SECTION 'D-D'
PS 218-0502
0

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ENGINEERS
NEW YORK N.Y. 10017

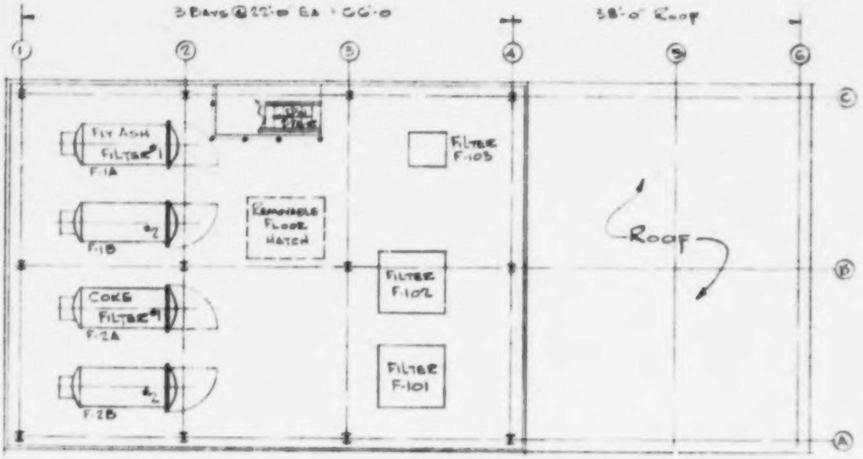
NATIONAL AIR POLLUTION
CONTROL ADMINISTRATION

ATOMICS INTERNATIONAL
MOLTEN CARBONATE PROCESS

CONCEPTIONAL SITE
ARRANGEMENT - SECTIONS

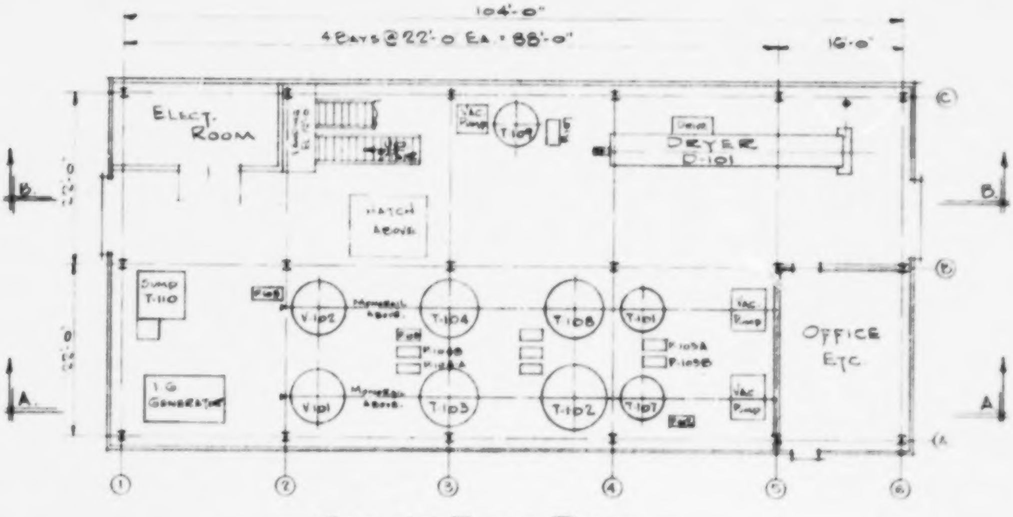
DWG. NO. PS 218 0502
REV. 0
SCALE 3/16" = 1'-0"

A



3 BAYS @ 22'-0 EA = 66'-0
38'-0" ROOF
1
2
3
4
5
6
C
B
A
FLY ASH FILTER #1
F-1A
#2
F-1B
COKE FILTER #1
F-2A
#2
F-2B
REMOVABLE FLOOR HATCH
FILTER F-103
FILTER F-102
FILTER F-101
ROOF

SECOND FLOOR PLAN



104'-0"
4 BAYS @ 22'-0 EA = 88'-0"
16'-0"
ELECT. ROOM
HATCH ABOVE
VAC PUMP
T-109
DEMO
DRYER D-101
SUMP T-110
I.G. GENERATOR
V-102
V-101
MONORAIL ABOVE
T-104
T-103
T-108
T-102
T-101
T-107
P-105B
P-105A
VAC PUMP
OFFICE ETC
B
A
1
2
3
4
5
6

GROUND FLOOR PLAN

SCALE: 1/8" = 1'-0"

FLY ASH FILTER
ELECT. ROOM
COKE FILTER
SUMP T-110

| INC. | DATE | REVISIONS | DR CH | APP | INC. | DATE | REVISIONS | DR CH | APP | NUMBER | REFERENCE DRAWINGS |
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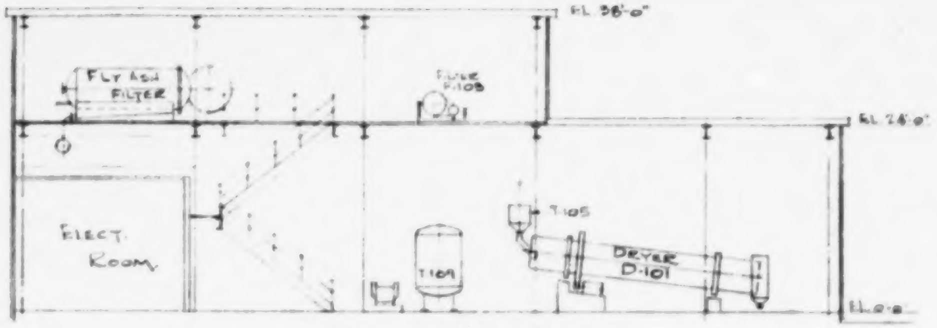
| | | | | | | | | | | | |

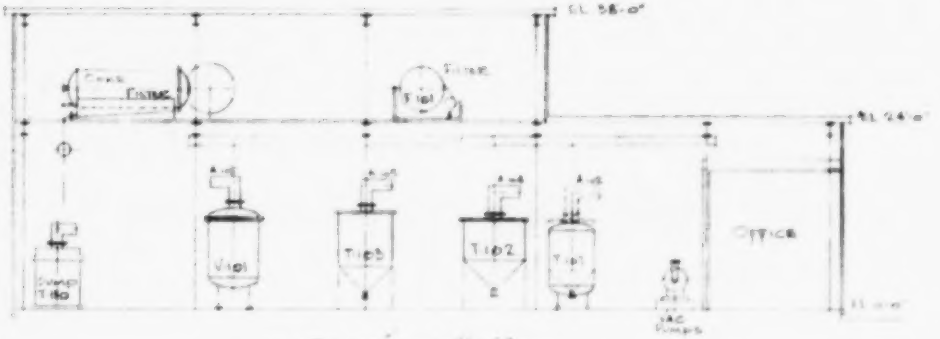
19 18 17 16 15 14 13 12 11 10 9

B

16'-0"
OFFICE
ETC
C
B
A
6
B
A


EL 38'-0"
EL 24'-0"
EL 0'-0"
FLY ASH
FILTER
FILTER
F-103
T-105
DRYER
D-101
T-104
ELECT.
ROOM

SECTION "B-B"


EL 38'-0"
EL 24'-0"
EL 0'-0"
FILTER
FILTER
F-101
SUMP
T-110
V-101
T-103
T-102
T-101
A-8
VAC
PUMPS
OFFICE

SECTION "A-A"

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NATIONAL AIR POLLUTION
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MOLTEN CARBONATE PROCESS

FILTER & RECOVERY PROCESS BLDG.
EQUIPMENT ARRANGEMENT

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DWG. NO. PS 218-0503 REV. 0

## 9. REFERENCES

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(1c) Part II - Process Chemistry, Regeneration.

(1d) Part III - Materials Studies.

(1e) Part IV - Contactor Development.

(1f) Part VI - Fly Ash Studies.

(1g) Part VI - Small Pilot Plant and Component Test Loop, Conceptual Design.

(1h) Part VII - Plant Analysis.

(1i) Progress Report No. 3 - October 28,1968 to July 31, 1969.

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(3) Johnstone, R.E. and Thring, M.W. "Pilot Plants, Models, and Scale-up Methods in Chemical Engineering" New York, McGraw-Hill Book Company,1957.

(4) Turnbull, A.G. "Thermal Conductivity of Molten Salts, II - Australian Journal of Applied Science 12: 324-329, 1961.

(5) Gambill, W.R. "Fused Salt Thermal Conductivity" Chemical Engineering 66: 129-130, August 10, 1959.

(6) Janz, G.J. and Lorenz,M.R. "Solid-Liquid Phase Equilibrium for Mixture of Lithium, Sodium and Potassium Carbonates" Journal of Chemical and Engineering Data 6 (3): 321-323, July, 1961.

(7) Marshall, W.L., Loprest, F.J. and Secoy, C.H. "The Equilibrium $Li_2CO_3$ (s)+$CO_2$+$H_2O$ $\longrightarrow$ 2 Li+2 $HCO_3$- at High Temperature and Pressure" Journal of the American Chemical Society 80: 5646-5648, November 5, 1958.

(8) "Modern Refractory Practice" Harbison-Walker Refractories Company.

(9) "Properties of Hitec" E.I. duPont, de Nemours & Company.

(10) "Coal Gasification Using Molten Sodium Carbonate" M.W. Kellogg & Company. Final Report Under Contract 14-01-0001-380 for U.S. Department of the Interior. September, 1967.

(11) "Systems Study for Control of Emissions- Primary Nonferrous Smelting Industry" Arthur G. McKee & Company. Final Report Under Contract PH-86-65-85 for U.S. Department of Health, Education and Welfare. June,1969.

## APPENDIX

### Construction Cost Estimate - Base Case Plant
### (Machinery & Equipment - Account 400)

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER NAPCA

LOCATION

PROJECT A.I. Molten Carbonate Process

DESCRIPTION Base Case
800 MW
3% S. in Coal
A/C 400

PROP. NO.
CONT. NO. PS-218
MADE BY J.S.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | Machinery & Equipment | | | | | | | | | |
| | Absorber Area | | | | | | 19 800 | 1,120000 | 330220 | 1,470020 |
| | Reducer Area | | | | | | 42400 | 540000 | 619180 | 1,201,580 |
| | Regenerator Area | | | | | | 8100 | 230000 | 149240 | 387340 |
| | Coke Handling Area | | | | | | 9100 | 74000 | 91400 | 174500 |
| | $M_2CO_3$ Make-Up Area | | | | | | 7200 | - | 89340 | 96540 |
| | $Li_2CO_3$ Recovery Area | | | | | | 15310 | - | 216540 | 231850 |
| | Ancillaries | | | | | | 1200 | - | 18300 | 19500 |
| | TOTAL A/C 400 | | | | | | 103 110 | 1,964000 | 1,514220 | 3,581330 |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 1

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
ABSORBER AREA
A/C 400

PROP. NO.
CONT. NO. PS.-218
MADE BY S.P. - J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº V-1A, 1B, 1C & 1D<br>ABSORBER:<br>28'-6" DIA. x 34'-0" STR. SIDE<br>MATL. CONST. = 347 STN. STL.<br>EQUIPPED WITH SPRAY NOZZLES<br>WT. = | 4 | ea. | | 280,000- | | | 1,120,000 | | 1,120,000 |
| | DEMISTER FOR ABOVE<br>MATL. CONST. = 347 STN. STL.<br>635 S.F. - INCLUDES SUPPT, ETC. | 4 | ea. | | | | 2000 | - | 40800 | 42800 |
| | ABSORBERS INSULATED WITH<br>5" THK. THERMOBESTOS - SEE<br>A/C 800 | | | | | | | | | |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 2

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER N.APCA

LOCATION

PROJECT A.I Molten Carbonate Process

DESCRIPTION 800 MW
3% Sulfur In Coal
ABSORBER AREA

A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.C J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG No V2D | 1 | ea. | | | | 400 | - | 18400 | 18800 |
| | ABSORBER PUMP TANK<br>7'-0" DIA. x 13'-0" LG.<br>MATL. CONST. 347 STN. STL,<br>Locate In Pit.<br>Wt. = 9000# | | | | | | | | | |
| | IMMERSION HEATER (ELEC.)<br>WITH ON-OFF THERMOSTAT<br>30 KW - For V-2A,B,C & D<br>MATL. CONST. 347 STN. STL. | 4 | ea. | | | | 800 | - | 2800 | 3600 |
| | TANK INSULATED WITH<br>5" THK. THERMOBESTOS - SEE<br>A/c 800 | | | | | | | | | |
| | TAG No V2A, B & C | 3 | ea. | | | | 1200 | | 16200 | 17400 |
| | ABSORBER PUMP TANK<br>6'-0" DIA. x 7'-0" LG.<br>MATL. CONST. 347 STN. STL. | | | | | | | | | |

CODE

(E 153)

DATE 9-2-70 REVISION NO. REVISION DATE PAGE NO. 3

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
ABSORBER AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. d.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG No P-1A(s), 1B(s) 1C(s) & 1D(s) | 8 | ea. | | | 9660 | 2800 | - | 77280 | 80080 |
| | ABSORBER PUMPS<br>720 G.P.M. - 112 psi ΔP<br>4'-0" LG. SHAFT · 2'-0" LG. TAIL PIECE<br>VERTICAL<br>MATL. CONST. · 347 STN. STL. | | | | | | | | | |
| | 125 H.P. MOTOR | 8 | ea. | | | 1630 | - | - | 13040 | 13040 |
| | TAG No F-1 A & B | | | | | | | | | |
| | FLY ASH FILTER<br>FIXED BLADE AGAINST ROTARY LEAVES.<br>LIQ. FLOW = 180,000 #/HR. - 1,000 S.F.<br>PRESSURE LEAF - 2 UNITS IN PARALLEL.<br>MATL. CONST. = 347 STN. STL.<br>INSTRUMENTATION NOT INCLUDED | 2 | ea. | | | 80,000 | 12400 | - | 160000 | 172400 |
| | TAG No B-2 | 1 | ea. | | | | 200 | | 1700 | 1900 |
| | FILTER DISPLACEMENT<br>BLOWER 150 ACFM - 3 PSI<br>STAIN. STL 304 | | | | | | | | | |
| | TOTAL · ABSORBER AREA | | | | | | 19800 | 1,120,000 | 330220 | 1,470020 |

CODE

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(E 153)

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.

3% SULFUR IN COAL

REDUCER AREA

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. J.J.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº B-1A, B, C & D | 4 | ea | | | 15600 | 4800 | - | 62400 | 67200 |
| | COMBUSTION AIR BLOWER<br>6000 CFM FREE AIR @7 psi<br>ΔP<br>MATL.: CONST.- CARB. STEEL | | | | | | | | | |
| | INCLUDES MOTOR - 300 H.P.<br>COMPLETE | | | | | | | | | |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 5

CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER N.APCA

LOCATION

PROJECT A I MOLTEN CARBONATE PROCESS

DESCRIPTION 800 MW
3% SULFUR IN COAL
REDUCER AREA
A/C400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J J
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº E-1A & 1B<br>REDUCER PRODUCT COOLER<br>AIR-COOLED UNIT WITH EXTERNAL AIR RECIRCULATION & STEAM COIL.<br>COMPLETE WITH 2-10 H.P. FANS EACH & ALL INSTRUMENTATION, ETC.<br>MATL. CONST.: 347 STN. STL.<br>Q each: $23,7 \times 10^6$ Btu/HR.<br>$\Delta P$ = 40 psi<br>13'-0" WIDE x 30'-0" LG. | 2 | ea. | | | | 8000 | - | 120000 | 128000 |

CODE

(E 153)

DATE 9-2-70 REVISION NO. REVISION DATE PAGE NO. 6

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I Molten Carbonate Process

DESCRIPTION 800 M W
3% Sulfur In Coal
REDUCER AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG Nº P-2A(S) & 2B(S) | 4 | ea. |  |  | 8225 | 3200 | – | 32 900 | 36 100 |
|  | REDUCER PUMP<br>585 G.P.M. - 156 psi ΔP<br>4'-0" Lg. Shaft - 4'-0" Lg. Tail Piece<br>VERTICAL<br>Matl. Const. - 347 Stn. Stl. |  |  |  |  |  |  |  |  |  |
|  | Motor - 150 H.P. | 4 | ea. |  |  | 1995 | · | – | 7980 | 7980 |
|  | TAG Nº V-3A, 3B, 3C & 3D | 4 | ea. |  | 135,000 |  |  | 540,000 |  | 540,000 |
|  | REDUCER (Stl.: A-204 Gr. A)<br>11'-0" Dia. x 20'-0" T&T - F&D Heads<br>9" Thk. Alundum Lining<br>4" Thk. Monofrax Lining.<br>Full Monofrax Partition<br>Air - Spargers. |  |  |  |  |  |  |  |  |  |
|  | Coke Blow Chamber<br>2 Req'd. Per Reducer | 8 | ea | (Allowance) |  |  | 1600 | - | 12 000 | 13600 |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 7

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 M.W

3% SULFUR IN COAL

LOCATION

REDUCER AREA

PROJECT A.I. MOLTEN CARBONATE PROCESS

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. J.J.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº E-2A, 2B, 2C & 2D<br>AIR-OXIDATION ZONE EXCHANGER<br>HEATING SURFACE 770 S.F.<br>MTL. TUBE SIDE - 347 STN. STL.<br>3'-6" DIA. X 29'0" OVERALL - INTERNALLY INSULATED ON AIR SIDE<br>Q each = $4.5 \times 10^6$ Btu/HR.<br>$\Delta P$: 6" $H_2O$ AIR-SIDE<br>EXCHANGER INSULATED WITH 5" THERMOBESTOS SEE A/c 800 | 4 | ea. | | | | 8000 | | 130 800 | 138800 |
| | TAG Nº F-2 A & B<br>COKE FILTER<br>FIXED BLADES AGAINST ROTARY BLADES<br>LIQUID FLOW 190,000 #/HR. 1000 SQ.FT.<br>PRESSURE LEAF - 2 UNITS IN PARALLEL;<br>MATL CONST. 347 STN. STL. | 2 | ea. | | | | 12400 | | 160 000 | 172400 |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 8

## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 MW
3% SULFUR IN COAL
REDUCER AREA
A/c 400

PROP. NO.
CONT. NO. PS - 218
MADE BY
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG Nº V-4A & 4B | 2 | ea. |  |  |  | 800 | - | 55200 | 56000 |
|  | REDUCER QUENCH TANK<br>9'-0" DIA. x 15'-0" LONG<br>MATL. CONST.: 347 STN. STL.<br>WT. = 12,500 # |  |  |  |  |  |  |  |  |  |
|  | IMMERSION HEATER (ELEC.)<br>WITH ON-OFF THERMOSTAT<br>30 KW - FOR ABOVE TANK<br>MATL. CONST. 347 STN. STL. | 2 | ea. |  |  |  | 400 | - | 1400 | 1800 |
|  | TANK INSULATED WITH<br>5" THK. THERMOBESTOS - SEE<br>A/c 800 |  |  |  |  |  |  |  |  |  |
|  | TAG Nº V-8A, 8B, 8C & 8D | 4 | ea. |  |  |  | 800 | - | 6500 | 7300 |
|  | COKE BIN<br>6'-0" x 6'-0" - 60° CONE BTM.<br>4 TON CAPACITY<br>MATL. CONST.: CARB. STL.<br>WT. = 3,200# ea. |  |  |  |  |  |  |  |  |  |

CODE

(E 153)

DATE 9-3-70 REVISION NO. REVISION DATE PAGE NO. 9

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER N.A.P.C.A

LOCATION

PROJECT AI Molten Carbonate Process

DESCRIPTION 800 M W
3% Sulfur In Coal
REDUCER AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F J.J
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № W-1A. 1B, 1C & 1D | 4 | ea. | | | | 2400 | - | 30000 | 32400 |
| | WEIGH BELT FEEDERS<br>8000#/HR MAX. EACH<br>INCLUDES LOCAL & REMOTE INSTRUMENTATION AND 2 H.P. MOTOR EA. | | | | | | | | | |
| | TOTAL - REDUCER AREA | | | | | | 42400 | 540000 | 619180 | 1,201,580 |

CODE

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DATE 9-3-70 REVISION NO. REVISION DATE PAGE NO. 10

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

**CUSTOMER** N.APCA

**LOCATION**

**PROJECT** A.I Molten Carbonate Process

**DESCRIPTION** 800 MW
3% Sulfur In Coal
REGENERATOR AREA
A/c 400

**PROP. NO.**
**CONT. NO.** PS-218
**MADE BY**
**APPROVED**

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG Nº E-4<br>REGENERATOR BOTTOMS COOLER<br>Air Cooled Unit With External Air Recirculation & Steam Coil Complete With 2-5 H.P. Fans Each. & All Instrumentation, Matl. Const. - 347 Stn. Stl.<br>Q each = $10 \times 10^6$ Btu/HR.<br>$\Delta P$ = 25 psi<br>8'-0" Wide × 24'-0" Lg. | 1 | ea. |  |  |  | 1800 | - | 35000 | 36800 |

CODE

DATE 9·8·70 REVISION NO. REVISION DATE PAGE NO. 11

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## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W
3% SULFUR IN COAL
REGENERATOR AREA
A/C 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG No E-5<br>REGENERATOR INTERMEDIATE COOLER<br>AIR COOLED UNIT WITH EXTERNAL AIR RECIRCULATION & STEAM COIL COMPLETE WITH 2-7½ H.P. FANS EACH & ALL INSTRUMENTATION MATL. CONST. - 347 STN. STL.<br>Q each = $15 \times 10^6$ Btu./HR.<br>$\Delta P$ = 25 psi<br>10'-0" WIDE x 24'-0" LG. | 1 | ea. | | | | 2000 | - | 45000 | 47000 |

CODE

(E 153)

DATE 9-4-70 REVISION NO. REVISION DATE PAGE NO. 12

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
REGENERATOR AREA
A/c 400

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG. Nº V-5 | 1 | ea. | | | | - | 230000 | - | 230000 |
| | REGENERATOR<br>18'-0" DIA. × 34'-6' STR. SIDE<br>F & D. HEADS<br>15 TRAYS. (BUBBLE CAP)<br>MATL. CONST. 347 STN. STL.<br>APPROX WT. 145,000# | | | | | | | | | |
| | REGENERATOR INSULATED WITH 5" THERMOBESTOS - SEE A/c 800 | | | | | | | | | |
| | TAG Nº V-6 | 1 | ea. | | | | 400 | - | 18500 | 18,900 |
| | REGENERATOR BOTTOMS PUMP TANK<br>7'-0" DIA. × 13'-0"<br>MATL. CONST. 347 STN. STL<br>WEIGHT = 9000# | | | | | | | | | |
| | IMMERSION HEATER (ELEC.)<br>WITH ON-OFF THERMOSTAT<br>30 KW FOR ABOVE TANK<br>MATL. CONST. 347 STN. STL. | 1 | ea. | | | | 200 | - | 700 | 900 |
| | INSULATE TANK WITH 5" THK. THERMOBESTOS. SEE A/c 800 | | | | | | | | | |

CODE

(E 153)

DATE 9-4-70 REVISION NO. REVISION DATE PAGE NO. 13

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 M.W

3% SULFUR IN COAL

REGENERATOR AREA

A/c 400

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

PROP. NO.

CONT. NO. PS.-218

MADE BY S.F. J.J.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG·Nº V·7 | 1 | ea. |  |  |  | 500 | - | 13500 | 14000 |
|  | REGENERATOR<br>INTERMEDIATE PUMP TANK |  |  |  |  |  |  |  |  |  |
|  | 6'-6" DIA x 12'-0" LG.<br>MATL. CONST. · 347 STN. STL.<br>WEIGHT.. 6000# |  |  |  |  |  |  |  |  |  |
|  | IMMERSION HEATER (ELEC.)<br>WITH ON-OFF THERMOSTAT<br>30 KW - FOR ABOVE TANK,<br>MATL. CONST. · 347 STN. STL. | 1 | ea. |  |  |  | 200 | - | 700 | 900 |
|  | INSULATE TANK WITH<br>5" THK. THERMOBESTOS · SEE A/c 800. |  |  |  |  |  |  |  |  |  |
|  | TAG Nº P-3A (s) | 2 | ea. |  |  | 8225 | 1600 | - | 16450 | 18050 |
|  | REGENERATOR BTMS PUMP<br>300 G.P.M. 147 psi ΔP<br>4'-0" LG. SHAFT - 2'-0" LG. TAILPIECE<br>VERTICAL · CANTILEVER<br>MATL CONST. 347 STN. STL. |  |  |  |  |  |  |  |  |  |
| CODE | MOTOR - 75 H.P. | 2 | ea |  |  | 1065 | - | - | 2130 | 2130 |

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DATE 9-  -70 REVISION NO. REVISION DATE PAGE NO. 14

## CONSTRUCTION COST ESTIMATE

## SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. Molten Carbonate Process

DESCRIPTION 800 MW
3% Sulfur in Coal
REGENERATOR AREA
A/c 400

PROP. NO.
CONT. NO. PS - 218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG № P-4A (S)<br>REGENERATOR INTERMEDIATE PUMP<br>350 G.P.M. - 101 psi ΔP<br>4'-0" Lg. Shaft. - 2'-0" Lg. Tail Piece<br>Vertical - Cantilever<br>Matl. Const. - 347 Stn. Stl. | 2 | ea. |  |  | 7470 | 1400 | - | 14940 | 16340 |
|  | Motor - 60 H.P. | 2 | ea. |  |  | 1160 | - | - | 2320 | 2320 |
|  | TOTAL - REGENERATOR AREA. |  |  |  |  |  | 8100 | 230000 | 149240 | 387340 |

CODE

(E 153)

DATE 9- -70 REVISION NO. REVISION DATE PAGE NO. 15

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I Molten Carbonate Process

DESCRIPTION 800 M.W
3% Sulfur In Coal
COKE HANDLING AREA
A/c 400

PROP. NO.
CONT. NO. PS-218.
MADE BY S.F. J.J
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № C-1<br>COKE RECEIVING HOPPER<br>Below Grade For R.R. Unloading<br>50 Ton Capacity<br>MATL. CONST. - CARB. STL. | 1 | ea. | | | | 400 | - | 4900 | 5300 |
| | TAG № C-1A<br>CRUSHER - 50"<br>50 Tons/Hr. 2" to 1/4"<br>2 ROW CAGE MILL<br>Includes · One-125H.P. Motor<br>One-100H.P. Motor | 1 | ea. | | | | 1500 | - | 23500 | 25000 |

CODE

(E 153)

DATE 9-5-70 REVISION NO. ______ REVISION DATE ______ PAGE NO. 16

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 MW
3% SULFUR IN COAL
COKE HANDLING AREA
A/C 400

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

PROP. NO.
CONT. NO. PS·218
MADE BY S.P. J.J
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG № G-1<br>TRANSFER CONVEYOR & FEEDER<br>50 TONS/HR.<br>INCLUDES 2 · 1 H.P. MOTORS | 1 | ea |  |  |  | 500 | - | 2500 | 3000 |
|  | TAG № G-2<br>BUCKET ELEVATOR<br>50 TONS/HR. - 25'-0" ℄ TO ℄<br>INCLUDES · ONE 3 H.P. MOTOR | 1 | ea. |  |  |  | 600 | - | 3500 | 4100 |

CODE

(E 153)

DATE 9 · 4 · 70 REVISION NO. REVISION DATE PAGE NO. 17

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER N.A.P.CA

LOCATION

PROJECT A.1 Molten Carbonate Process

DESCRIPTION 800 MW
3% Sulfur in Coal
COKE HANDLING AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.L.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº G-3<br>BUCKET ELEVATOR<br>50 Tons/HR - 60'-0" ℄ To ℄<br>Includes One 5 H.P. Motor. | 1 | ea. | | | | 800 | - | 6500 | 7300 |
| | TAG Nº G-4<br>REVERSING BELT CONVEYOR<br>50 Tons/HR. - 30 Foot<br>Enclosed -<br>Includes - One - 3H.P. Motor. | 1 | ea. | | | | 700 | - | 4500 | 5200 |

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DATE 9-4-70 REVISION NO. REVISION DATE PAGE NO. 18

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W
3% SULFUR IN COAL
COKE HANDLING AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG Nº G-5<br>COKE BELT CONVEYOR<br>10" WIDE x 90'-0" ℄ to ℄<br>INCLUDES DISTRIBUTION CONVEYOR WITH BELT PROPELLED TRIPPER & ONE - 5 H.P. MOTOR. | 1 | ea. |  |  |  | 1200 | - | 13000 | 14200 |
|  | TAG Nº G-6<br>DUST COLLECTOR<br>INCLUDES - FAN & 5 H.P. MOTOR. | 1 | ea. | (ALLOWANCE) |  |  | 900 | - | 6000 | 6900 |
|  | TAG Nº G-5A<br>ELEVATING BELT CONVEYOR<br>18" WIDE x 170'-0" INCLUDES MOTOR & DRIVE | 1 | ea. |  |  |  | 1400 | - | 16500 | 17900 |

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(E 153)

DATE 1-4-70 REVISION NO. REVISION DATE PAGE NO. 19

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER N.A.P C A

LOCATION

PROJECT A.I. Molten Carbonate Process

DESCRIPTION 800 M W
3% Sulfur In Coal
COKE HANDLING AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG. Nº G-7 & G-8<br>COKE SILO DUST COLLECTOR<br>Mounted on top of T-1 & T-2<br>Includes One 2 H.P. Fan each. | 2 | ea. | | | | 300 | - | 2000 | 2300 |
| | TAG Nº S-1<br>COKE SCREEN<br>50 Tons/Hr. 1/4"<br>Rotex - 5'-0" x 12'-0"<br>Includes- 7½ H.P. Motor | 1 | ea. | | | | 800 | - | 8500 | 9300 |

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(E 153)

DATE 7-4-70 REVISION NO. REVISION DATE PAGE NO. 20

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAP.CA
LOCATION
PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W
3% SULFUR IN COAL
COKE HANDLING AREA
A/C 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № T-1 & T-2<br>COKE STORAGE SILO<br>500 TON - LIVE STORAGE EACH<br>CONCRETE STAVE<br>30'-0" DIA. X 60'-0" HIGH<br>DOES NOT INCLUDED FOUNDATION | 2 | ea. | | | | - | 74000 | - | 74000 |
| | TOTAL - COKE HANDLING AREA | | | | | | 9100 | 74000 | 91400 | 174500 |

CODE

(E 153)

DATE 1-4-70 REVISION NO. REVISION DATE PAGE NO. 21

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W
3% SULFUR IN COAL
$M_2CO_3$ MAKE-UP AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № G-9<br>$M_2CO_3$ BUCKET ELEVATOR<br>25 TONS/HR. - 50FT. LIFT<br>INCLUDES ONE 5HP. MOTOR | 1 | ea. | | | | 800 | - | 5000 | 5800 |
| | TAG. № G-10<br>$M_2CO_3$ CONVEYOR<br>2 TONS/HR. -<br>INCLUDES - ONE 2H.P. MOTOR | 1 | ea. | | | | 600 | - | 3500 | 4100 |
| | TAG. № G-11<br>$M_2CO_3$ SILO FEED CONVEYOR<br>30'-0" LG<br>INCLUDES TRIPPER<br>& ONE 3H.P. MOTOR | 1 | ea. | | | | 800 | - | 8000 | 8800 |

CODE

(E 153)

DATE 9-4-70 REVISION NO. REVISION DATE PAGE NO. 22

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M W
3% SULFUR IN COAL
$M_2CO_3$ MAKE-UP AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY G.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG № W-2, 3 & 4<br>WEIGH FEEDER<br>100 LBS/HR. CAPACITY<br>WITH REMOTE INSTRUMENTS<br>& ONE H.P. MOTOR | 3 | ea |  |  |  | 2300 | - | 25000 | 27300 |
|  | TAG № V-9<br>$M_2CO_3$ MELT TANK<br>6'-0" DIA. x 6'-0" LG.<br>MATL. CONST. 347 STN. STL.<br>WEIGHT 5,500 LBS. | 1 | ea |  |  |  | 400 | - | 11300 | 11700 |
|  | IMMERSION HEATER (ELEC.)<br>WITH ON-OFF THERMOSTAT.<br>125 KW ea. TOT. 250 KW.<br>MATL. CONST. 347 STN. STL. | 2 | ea |  |  |  | 500 | - | 4600 | 5100 |
| CODE | INSULATE TANK WITH 5" THK.<br>THERMOBESTOS - SEE A/c 800 |  |  |  |  |  |  |  |  |  |

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DATE 9-4-70 REVISION NO. REVISION DATE PAGE NO. 23

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A I MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M W.
3% SULFUR IN COAL
$M_2CO_3$ MAKE-UP AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № T-3, 4 & 5 | | | | | | | | | |
| | $Na_2CO_3$ SILO, $K_2CO_3$ SILO & $Li_2CO_3$ SILO | 3 | ea | | | | 1200 | - | 27000 | 28200 |
| | 10'-0" DIA. x 20'-0" STR. - 60° CONE<br>MATL. CONST.: CARB. STL. | | | | | | | | | |
| | DUST COLLECTOR FOR ABOVE SILOS | 3 | ea. | | | | 400 | - | 3000 | 3400 |
| | TAG № P-5 | 1 | ea. | | | | 200 | - | 1750 | 1950 |
| | $M_2CO_3$ MAKE-UP PUMP | | | | | | | | | |
| | 4 GPM 12 psi<br>VERTICAL<br>3'-0" SHAFT - 2'-0" TAILPIECE<br>MATL. CONST. 347 STN. STL. | | | | | | | | | |
| | MOTOR - 5 H.P | 1 | ea. | | | | - | - | 190 | 190 |
| | TOTAL - $M_2CO_3$ MAKE-UP AREA | | | | | ✓ | 7200 | - | 89340 | 96540 |

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DATE 9-70 REVISION NO. REVISION DATE PAGE NO. 24

## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER NAPCA

LOCATION

PROJECT A.I. Molten Carbonate Process

DESCRIPTION 800 M W

3% Sulfur In Coal

$Li_2CO_3$ RECOVERY AREA

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. N.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № B-101 | 1 | ea | | | | 200 | - | 1000 | 1200 |
| | EXHAUST FAN | | | | | | | | | |
| | 3600 CFM @ 3" $H_2O$ - 5 H.P. | | | | | | | | | |
| | TAG № B-102 | 1 | ea. | | | | 300 | | 1700 | 2000 |
| | HOT AIR BLOWER | | | | | | | | | |
| | 25 H.P. Motor For Above | | | | | | - | - | 500 | 500 |

CODE

DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 25

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CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A I Molten Carbonate Process

DESCRIPTION 800 M W
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA
A/c 400

PROP. NO.

CONT. NO. PS - 218

MADE BY S.P. N.R.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG № D-101 | 1 | ea |  |  |  | 1500 | - | 26700 | 28200 |
|  | $Li_2CO_3$ DRYER |  |  |  |  |  |  |  |  |  |
|  | 570 LBS/HR. DRY $Li_2CO_3$<br>4540 MOISTURE FEED<br>DIRECT FIRED 800,000 Btu/HR.<br>NAT. GAS<br>4'-0" DIA. x 30'-0" LG. COMPLETE<br>WITH 7½ HP DRIVE, 5 HP. FAN &<br>BAG FILTER<br>MATL. CONST. - CARB. STL. |  |  |  |  |  |  |  |  |  |
|  | FEEDER INCL. 2 HP. MOTOR | 1 | ea. |  |  |  | 200 | - | 1500 | 1700 |

CODE

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DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 26

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER N.A.P.C.A

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA

A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.R. H.R.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG No F-101<br>$Li_2CO_3$ FLY ASH FILTER<br>150 S.F. - 6'-0" DIA x 8'-0" FACE<br>COMPLETE WITH:<br>VACUUM PUMP - 50 H.P.<br>T 107<br>P-102 PUMP & 2 HP. MOTOR<br>FILTER DRIVES: 1 HP. MOTOR<br>AGITATOR DRIVES: 1 H.P. MOTOR<br>MATL. CONST.: CARB. STL. | 1 | ea. | | | | 1800 | - | 35000 | 36800 |

CODE

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DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 27

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA

A/c 400

PROP. NO.

CONT. NO. PS.-218

MADE BY S.F. M.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № F-102<br>FLY ASH FILTER<br>(SAME AS F-101) | 1 | ea. | | | | 1800 | - | 35000 | 36800 |
| | TAG № F-103<br>$Li_2CO_2$ FILTER<br>30 S.F.<br>COMPLETE WITH:<br>VACUUM PUMP - 20 H.P.<br>T-109<br>P-107 PUMP & 1½ H.P. MOTOR<br>AGITATOR DRIVE = ½ H.P. MOTOR<br>FILTER DRIVE = ½ H.P. MOTOR | 1 | ea. | | | | 1600 | | 20000 | 21600 |

CODE

(E 153)

DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 28

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 M.W.
3% SULFUR IN COAL

LOCATION

$Li_2$ $CO_3$ RECOVERY AREA

PROJECT A1 MOLTEN CARBONATE PROCESS

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. N.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG № G-101<br>DRIED $Li_2CO_3$ CONVEYOR<br>REDLER TYPE<br>≈ 40'-0" RUN<br>INCLUDES 2 HP. MOTOR<br>MATL. CONST. = CARB. STL. | 1 | ea |  |  |  | 400 | - | 3000 | 3400 |

CODE

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DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 29

**CONSTRUCTION COST ESTIMATE**

**SINGMASTER & BREYER**

CUSTOMER NAPCA

DESCRIPTION 800 M.W.

3% SULFUR IN COAL

LOCATION

$Li_2CO_3$ RECOVERY AREA

PROJECT A.I MOLTEN CARBONATE PROCESS

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F  M.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS |  |  | ESTIMATED COST CENTS OMITTED |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT |  |  |  |  |  |  |  |  |  |
|  | TAG Nº P-101 A & B<br>$Li_2CO_3$ FLY ASH FILTER FEED PUMP<br>20 GPM @ 75'-0" TDH<br>SPEC. GR. 1.1<br>INCLUDING 1½ HP MOTOR<br>MATL. CONST. - CAST IRON | 2 | ea |  |  |  | 300 | - | 1400 | 1700 |
|  | TAG Nº P-102 | 1 | ea. |  |  |  | FURNISHED WITH F-101 |  |  | - |
|  | TAG Nº P-103 A & B<br>SLURRY DISPOSAL PUMP<br>20 GPM @ 70'-0" TDH<br>SPEC. GR. 1.1<br>INCLUDING 1½ H.P. MOTOR<br>MATL. CONST. - CAST IRON | 2 | ea. |  |  |  | 300 | - | 1380 | 1680 |

CODE

DATE 9-10-76 REVISION NO. REVISION DATE PAGE NO 30

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## CONSTRUCTION COST ESTIMATE

**SINGMASTER & BREYER**

CUSTOMER NAPCA

LOCATION

PROJECT A.I Molten Carbonate Process

DESCRIPTION 800 M.W
3% Sulfur In Coal
$Li_2CO_3$ RECOVERY AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. H.P.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № P-104A<br>FLY ASH FILTER FEED PUMP<br>30 GPM @ 70'-0" TDH<br>SPEC. GR.=1.1 - HORIZONTAL<br>INCLUDES 1HP MOTOR<br>MATL. CONST. - CAST IRON | 1 | ea. | | | | 180 | - | 750 | 930 |
| | TAG № P-104B<br>SPARE PUMP FOR P-104A & P-106 | 1 | ea. | | | | 180 | - | 750 | 930 |
| | TAG № P-105<br>$Li_2CO_3$ REACTOR PRODUCT PUMP<br>200 GPM @ 15'-6" TDH<br>SPEC. GR.: 1.1 - HORIZONTAL<br>INCLUDES 1½ H.P. MOTOR<br>MATL. CONST. : CAST IRON | 1 | ea. | | | | 200 | - | 900 | 1100 |

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DATE 9-11-70 REVISION NO. REVISION DATE PAGE NO. 31

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## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M W
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.P. N.P.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № P-106 | 1 | ea. | | | | 180 | - | 750 | 930 |
| | $Li_2CO_3$ FILTER FEED PUMP<br>30 GPM @ 70'-0" TDH<br>SPEC. GR. = 1.1 · HORIZONTAL<br>INCLUDES 1 HP MOTOR<br>MATL. CONST. = CAST IRON | | | | | | | | | |
| | TAG № P-107 | 1 | ea. | | | | FURNISHED WITH F-103 | | | - |
| | TAG № P-108 & P109 | 2 | ea. | | | | 400 | - | 1800 | 2200 |
| | $Li_2CO_3$ REACTOR FEED PUMP<br>200 GPM @ 15' TD.H · SPEC. GR. 1.1<br>MATL. CONST. = CAST IRON<br>INCLUDES 1½ H.P. MOTOR | | | | | | | | | |

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(E 153)

DATE 9-11-70 REVISION NO. REVISION DATE PAGE NO. 32

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

DESCRIPTION 800 MW

3% SULFUR IN COAL

$Li_2CO_3$ RECOVERY AREA

A/c 400

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. N.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº T-101<br>FLY ASH CAKE SLURRY TANK<br>5'-0" DIA. x 6'-0" STR. - 60° CONE BTM. - OPEN TOP<br>MATL. CONST. : CARB. STL. | 1 | ea. | | | | 300 | - | 3500 | 3 800 |
| | TAG Nº A-102<br>AGITATOR FOR TANK T-101<br>INCLUDES 3 H.P. MOTOR | 1 | ea. | | | | 120 | - | 500 | 620 |
| | TAG Nº T-102<br>$Li_2CO_3$ FLY ASH FILTER CAKE RECEIVER<br>8'-0" DIA. x 5'-0" STR. - 60° CONE BTM. - OPEN TOP<br>MATL. CONST. - CARB. STL. | 1 | ea. | | | | 300 | - | 4200 | 4500 |
| | TAG Nº A-104<br>AGITATOR FOR TANK T-102<br>INCLUDES 5 H.P. MOTOR | 1 | ea. | | | | 150 | | 600 | 750 |

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DATE 9-11-70 REVISION NO. REVISION DATE PAGE NO. 33

CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

DESCRIPTION 800 M W

3% SULFUR IN COAL

LOCATION

$Li_2CO_3$ RECOVERY AREA

PROP. NO.

CONT. NO. PS-218

PROJECT A.I. MOLTEN CARBONATE PROCESS

MADE BY S.F. N.P.

A/c 400

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № T-103 | 1 | ea. | | | | 300 | - | 3900 | 4200 |
| | $LiHCO_3$ REACTOR PRODUCT SURGE TANK<br>7'-0" DIA. x 7'-0" STR.<br>90° CONE BTM. - OPEN TOP<br>MATL. CONST = CARB. STL. | | | | | | | | | |
| | TAG № A-105 | 1 | ea. | | | | 150 | - | 550 | 700 |
| | AGITATOR FOR TANK T-103<br>INCLUDES 5 H.P. MOTOR | | | | | | | | | |
| | TAG № T-104 | 1 | ea | | | | 300 | - | 3900 | 4200 |
| | $Li_2CO_3$ REACTOR PRODUCT SURGE TANK<br>7'-0" DIA. x 7'-0" STR.<br>90° CONE BTM. - OPEN TOP<br>MATL. CONST: CARB. STL. | | | | | | | | | |
| | TAG № A-107 | 1 | ea. | | | | 150 | - | 550 | 700 |
| | AGITATOR FOR TANK T-104<br>INCLUDES 5 H.P MOTOR | | | | | | | | | |

CODE

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DATE 9-11-70 REVISION NO. REVISION DATE PAGE NO. 34

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA
LOCATION
PROJECT A.I MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. R.P.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº T-105<br>WET $Li_2CO_3$ SURGE DRUM<br>4'-0" x 4'-0" x 4'-0" - 1/4" THK.<br>ATMOS PRESS.<br>MATL. CONST = CARB, STL. | 1 | ea. | | | | 100 | - | 1400 | 1500 |
| | TAG Nº T-106<br>$Li_2CO_3$ STORAGE<br>10'-0" DIA. x 9'-0" STR.<br>60° CONE BTM - FLAT TOP<br>MATL. CONST = CARB. STL. | 1 | ea. | | | | 400 | - | 7200 | 7600 |

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(E 153)

DATE 9-11-70 REVISION NO. ______ REVISION DATE ______ PAGE NO. 35

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA
A/c 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. N.P.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº T-107<br>SOLUBLE SALT RECEIVER | 1 | ea. | | | | INCLUDED | IN COST | OF F-101 | – |
| | TAG Nº T-108<br>$LiHCO_3$ FILTRATE RECEIVER | 1 | ea. | | | | INCLUDED | IN COST | OF F-102 | – |
| | TAG Nº T-109<br>$Li_2CO_3$ FILTRATE RECEIVER | 1 | ea. | | | | INCLUDED | IN COST | OF F-103 | - |

CODE

(E 153)

DATE 9-10-70 REVISION NO. REVISION DATE PAGE NO. 36

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER N. A P. C. A.

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.

3% SULFUR IN COAL

$Li_2CO_3$ RECOVERY AREA

A/c 400

PROP. NO.

CONT. NO. PS-218

MADE BY S.F. N.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº T-110<br>DISSOLVING SUMP<br>CONCRETE - 2 COMPARTMENTS<br>6'-0" x 6'-0" x 6'-0" AGITATION COMP.<br>2'-0" x 6'-0" x 6'-0" PUMPING COMP. | 1 | ea. | | | | 800 | - | 600 | 1400 |
| | TAG Nº A-101<br>AGITATOR FOR SUMP T-110<br>INCLUDING 5 H.P. MOTOR | 1 | ea. | | | | 200 | - | 1500 | 1700 |

CODE

(E 153)

DATE 9-10-70 REVISION NO. REVISION DATE

## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 M.W.
3% SULFUR IN COAL
$Li_2CO_3$ RECOVERY AREA
A/C 400

PROP. NO.
CONT. NO. PS-218
MADE BY S.F. N.P.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG № V-101 | 1 | ea. | | | | 300 | - | 5100 | 5400 |
| | $LiHCO_3$ REACTOR<br>6'-6" DIA. x 8'-0" T.L. 100 LB. DESIGN PRESS.<br>MATL. CONST. : CARB. STL. | | | | | | | | | |
| | TAG № A-103 | 1 | ea. | | | | 150 | - | 550 | 700 |
| | AGITATOR FOR REACTOR V-101<br>INCLUDING 5 H.P. MOTOR | | | | | | | | | |
| | TAG № V-102 | 1 | ea | | | | 300 | - | 5100 | 5400 |
| | $Li_2CO_3$ REACTOR<br>6'-6" x 8'-0" T.L. - 10 LB. DESIGN PRESS<br>MATL. CONST. : CARB. STL. | | | | | | | | | |
| | TAG № A-106 | 1 | ea. | | | | 150 | - | 550 | 700 |
| | AGITATOR FOR REACTOR V-102<br>INCLUDING 5 H.P. MOTOR | | | | | | | | | |

CODE

(E 153)

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## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

DESCRIPTION 800 MW

3% SULFUR IN COAL

$Li_2CO_3$ RECOVERY AREA

A/c 400

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

PROP. NO.

CONT. NO. PS - 218

MADE BY SF. N.P.

APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | TAG Nº X-101 | 1 | ea. | | | | 2000 | - | 47000 | 49000 |
| | $CO_2$ GENERATOR (12% $CO_2$) | | | | | | | | | |
| | 70,000 SCFM OF GAS<br>8,500 SCFM OF $CO_2$<br>FUEL = NATURAL GAS 8,000 SCFM | | | | | | | | | |
| | I. G. GENERATOR BLOWER 30 H.P. MOTOR | | | | | | | | | |
| | COMPRESSOR TO SUPPLY 75 psi GAS 200 H.P. MOTOR | | | | | | | | | |
| | COOLING WATER = 75 GPM | | | | | | | | | |
| | ALL OF THE ABOVE SKID MOUNTED | | | | | | | | | |
| | | | | | | | | | +10 | +10 |
| | TOTAL · $Li_2CO_3$ RECOVERY | | | | | | 15310 | - | 216540 | 231 850 |

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## CONSTRUCTION COST ESTIMATE

SINGMASTER & BREYER

CUSTOMER NAPCA

LOCATION

PROJECT A.I. MOLTEN CARBONATE PROCESS

DESCRIPTION 800 MW
3% SULFUR IN COAL
ANCILLARIES
400

PROP. NO.
CONT. NO. PS.-218
MADE BY S.F. J.J.
APPROVED

| ACCOUNT NUMBER | ITEM & DESCRIPTION | QUANTITY | UNIT | UNIT COSTS | | | ESTIMATED COST CENTS OMITTED | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LABOR | SUB CONTR | MAT'L | LABOR | SUB CONTRACTS | MATERIALS | TOTAL |
| 400 | MACHINERY & EQUIPMENT | | | | | | | | | |
| | INSTRUMENT AIR COMPRESSOR AND RECEIVER - 50 H.P. MOTOR. | 1 | LOT | | | | 900 | - | 12300 | 13200 |
| | INSTRUMENT AIR DRYER - 10 KW. | 1 | ea. | | | | 300 | - | 6000 | 6300 |
| | TOTAL - ANCILLARIES | | | | | | 1200 | - | 18300 | 19500 |

CODE

(E 153)

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